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# MICROMETRICAL MEASURES

OF

# GASEOUS SPECTRA UNDER HIGH DISPERSION.

BY

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# XXIV.—*Micrometrical Measures of Gaseous Spectra under High Dispersion.* By C. PIAZZI SMYTH, F.R.S.E., and Astronomer-Royal for Scotland. (Plates XLVIII. to LXXVIII.)

(Read 16th June 1884.)

CONTENTS.

APPENDIX IV. Plates—*continued.*

| PLATES. | | |
|---|---|---|
| LV. | 8 | CO in Vacuum tubes, Red band thereof, and Scarlet band, on a 40-foot Spectrum length. |
| LVI. | 9 | " " Orange band and Yellow band. |
| LVII. | 10 | " " Yellow band and Citron band. |
| LVIII. | 11 | " " Green band thereof and Blue band. |
| LIX. | 12 | " " Indigo band and Violet band. |
| LX. | 13 | H in Vacuum tubes, Early Red; Red to Scarlet, region; on a 40-foot Spectrum length. |
| LXI. | 14 | " " Orange, Yellow, and Citron. |
| LXII. | 15 | " " Citron to Green. |
| LXIII. | 16 | " " Green, Glaucous, and Blue. |
| LXIV. | 17 | " " Blue, Indigo, and Violet. |
| LXV. | 18 | " " Violet continued. |
| LXVI. | 19 | O in Vacuum tubes, Ultra-Red, Red, and Scarlet, regions on a 40-foot Spectrum length. |
| LXVII. | 20 | " " Orange and Yellow. |
| LXVIII. | 21 | " " Citron to Green. |
| LXIX. | 22 | " " Glaucous to Violet. |
| LXX. | 23 | N in Vacuum tubes, Ultra-Red regions thereof, adapted to a 40-foot Spectrum length. |
| LXXI. | 24 | " " Ultra Red, Red, and Scarlet. |
| LXXII. | 25 | " " Yellow and Citron. |
| LXXIII. | 26 | " " Citron and Green. |
| LXXIV. | 27 | " " Glaucous and Blue. |
| LXXV. | 28 | " " Blue and Indigo. |
| LXXVI. | 29 | " " Violet; all the above Plates have scales in terms of Wave-number *per* British Inch. |
| LXXVII. | 30 | Folding Index Map of all the above, and some other, gases, at both high and low temperatures, and throughout the visible Spectrum, but greatly reduced in scale. |
| LXXVIII. | 31 | Folding plate of Green CO's extra-green-CH portion; full size of original record, viz., for a 120-foot Spectrum length, with explication of its double arithmetical series. |

APPENDIX V. On the numerical Wave-number Spectrum Scale adopted here.

## INTRODUCTION.

After the Royal Society, Edinburgh, had been pleased in 1880 to accept and print my paper on the general appearance of Gaseous spectra as seen on a very small scale, but complete on that scale from one end to the other of the visible spectrum, I was desirous to present them with some very highly Dispersed and much magnified views of the more interesting and probably crucial portions of the most important of those spectra.

An example of acting on that principle had already been set in the admirable essay of MM. ANGSTROM and THALEN, published in the *Upsala Transactions* for 1875. For there, both in the Plates and letterpress, the final portions entitled "Mesures Micométriques" are very largely magnified representations of certain small parts of what went before.

But just as occurred in the earlier division of that great work, so also in this later portion of it, there appeared to me to be too few gases, and too few portions of their spectra treated of, to supply a sufficiently comprehensive basis for this branch of science.

Neither again in their *Mesures Micrométriques* did the Dispersion power which those eminent philosophers employed, appear sufficient either in amount

or definition to bring out many of the exquisite and close-set details which spectroscopy is beginning to demand in the present day for any and every gas that is now observed. And this, too, although those Upsala results did most honourably transcend all others at the time they were published, and for many years afterwards, indeed almost, if not quite, up to the present time.

Hence I have felt it incumbent on myself, before venturing to trouble this Society with new versions of any old phenomena, not only to increase the range of subjects treated of, but to improve the instrumental apparatus employed on all of them, until it was capable of some very remarkable performances in the way at least of differential mensurations in the field of view or near it.

Of such differences, however, only. For temperature changes in the fluid prisms, although greatly reduced by a variety of contrivances, were yet continually at work, altering to so sensible an extent the value of the Dispersion scale from its distant zero, as to prevent the absolute places given by this very lately put-together apparatus being anything better than extremely rough when over long ranges.*

But condoning that one weakness, for the sake of other advantages, the strength of the instrument for micrometrical detection and record of small differences may be indicated thus—

(A) The one-prism spectroscope employed in my collective and rudimentary paper of 1880, possessed a little more than 3° of Dispersion from A to H, with a magnifying power on the telescope of 10 diameters; virtually broadening those 3° to 30°.

(B) The apparatus employed by MM. ANGSTROM and THALEN for their *Mesures Micrométriques,* as nearly as I can gather in a general way, must have had at the utmost a Dispersion A to H of 24°, with a magnifying power of nearly the same number of diameters; or equivalent virtually to a spectrum 600° long.

(C) While my present arrangement has 60° of Dispersion A to H, with magnifying powers on the telescope of inspection rising from 12 to 36, and a further mechanical magnifying in the recording apparatus of 5 times; equivalent to 9000 of the same degrees altogether; or to the action of 1800 simple prisms of 60° refracting angle in white flint-glass, viewed with the naked eye.†

* By observations on Green CO on November 3, 4, and 5, it was ascertained that, after everything had been done at the place that could well be done to secure constancy of temperature in the bisulphide of carbon prisms employed, a slow fall of 1° Fahr. increased the Dispersive power of the collective train of prisms by 0·727 of a Revolution of the very coarse screw motion; or by close upon 10 inches on the surface of the recording barrel. The interval of time therefore between any two mutually dependent observations was, after that, made as short as possible.

† The diameter of the objectives was the same as in my earlier apparatus, viz., 2·25 inches, and the refracting faces of the prisms presented nearly the same breadth to the entering ray.

To which qualities were added, when assisted however by certain more intense illuminations, a transparency nearly as great, and a definition in certain parts of the spectrum considerably better, than I have seen in almost any smaller instrument.

For this latter excellence I have chiefly to thank Mr ADAM HILGER, and to laud the extreme skill and perfection wherewith he constructed both the glass cores of the bisulphide prisms, and their all-important anti-prisms out of admirably hard, white, and uniform crown glass. The Micrometrical recording apparatus was exquisitely constructed by Messrs T. COOKE & SONS of York, to whom I am therefore much obliged; while I am further quite unspeakably indebted to the progress of Chemical Science, which has, in recent years entirely freed bisulphide of carbon from the horrors of its ancient smell, and has given us a fluid perfectly colourless, nearly inodorous, exceedingly transparent, and endued with less refraction but more concomitant Dispersion, than anything else under the Sun.

In discussing therefore the results obtained with all these advantages, I shall not only refer to MM. ANGSTROM and THALEN'S now nine year old, yet still most excellent, essay, but shall consider it a duty to seek out later and more advanced works, if they exist, elsewhere. Paying particular attention to the recent Reports of the British Association's very powerfully constituted Committee * for reporting on our present knowledge of Spectrum Analysis in 1880, 1881, 1882, and 1883.

For their admirable digests of all that has gone before, and all that has come up to their own time, in the now voluminous bibliography of the spectrum, enables every one to locate the place, and assign the value of any new observation both with high certainty and the least loss of time.

## PART I.

### THE FIRST GAS TO BE EXAMINED, AND UNDER WHAT CONDITIONS.

As my object has been to a large extent to pass over superficial variations, and arrive, if possible, at the great constants of Nature in this department,—

* The Members of the Committee are given thus—

Professor DEWAR.
Dr WILLIAMSON.
Dr MARSHALL WATTS.
Capt. W. DE W. ABNEY, R.E.
Mr STONEY.
Professor HARTLEY.
Professor M'LEOD.
Professor CAREY FOSTER.
Professor A. K. HUNTINGTON.
Professor EMERSON REYNOLDS.
Professor REINOLD.
Professor LIVEING.
Lord RAYLEIGH.
Dr SCHUSTER, and
Mr W. CHANDLER ROBERTS, *Secretary*.

it would seem that I ought to begin with the simple, elementary gases; and afterwards touch on their compounds if desired.

But the practical methods of inductive inquiry into Nature, oblige me to proceed in exactly the opposite manner, and begin, as did also the great Upsala leaders, with the manufactured compound gas most immediately at hand in any and every situation in life, viz., illuminating gas, whether of coal, oil, wax, or tallow.

There may be, as we shall see presently, some difficulty in deciding on the chemical interpretation to be put on the spectrum thence obtained, but there is none in procuring a view of it; for whether we observe the blue flame of a blow-pipe of coal-gas and air, or the blue base of an upright flame of either those or any other of the ordinary illuminants of night employed by man, burning in the open air,—there appears to be always the same identical spectrum present, differing in no one case from another, except in degree of brilliancy.

Were we to burn the illuminant in a current of pure oxygen, something additional might be seen. But I have purposely refrained from doing that, and confined myself, in this part of the inquiry, to the grand aerial constant for all men, compound though it be, of the earth's atmosphere, for the sole elementary aid to combustion, as a mode of obtaining incandescent temperature.

To make the effects of that, however, more visible than usual, I have employed a blow-pipe nearly a foot long; with coal-gas in quantity from the service pipes of the house, but urged in intensity by air from a bag under pressure equivalent to 6 or 8 inches of water: and have further always placed the flame thence procured "end-on" to the spectroscope's slit, in the manner described to, and approved by, the Royal Scottish Society of Arts several years ago. Thence results what the Brittish Association calls,

### The Candle-Spectrum, in Air,

or, as named here, for reasons presently to appear, CH, *i.e.*, Carbo-Hydrogen, in Blow-Pipe Flame.

Having been introduced to this Society nearly thirty years ago, by our respected Fellow, Professor Swan, this particular spectrum will doubtless be well known to every one present, as offering a charmingly simple arrangement of five bands, most aptly to be compared to the human hand. For the first of them, orange coloured, and therefore in the orange region of the spectrum, is comparatively thin and weak, say like the little finger. The second, citron coloured, much stronger like the next finger. The third in the green, the brightest and strongest of the whole, like the middle finger. The fourth, in the blue, intermediate for strength between the first and second, like the index

finger; while the fifth, in the violet, is not of the build of any of the other bands; you may say not a finger at all, but shorter, broader, sturdier, like the thumb.

Viewed in any ordinary single-prism spectroscope, each of the first four of these bands begins on the red side with a strong line, followed by two, three or more similar lines, but in decreasing brightness and lessening distance, interspersed with haze; while the fifth band seems to be composed of nothing but haze.

This luminous hazy mist has, however, been occasionally seen by some individuals with powerful spectroscopes to be more or less resolvable into faint and exceedingly close lines or linelets. And now, with my new spectroscope, I have not only seen it *all* so resolved, but have been able to measure almost every linelet by micrometer, until at last they became too faint to be distinguished in any manner whatever.

The record thus procured, proving so neatly that there is no waste, neglected, unordered or accidental material in the spectrum of this cheapest of all the gases, was obtained on the instrument in so very magnified a condition, that the whole visible spectrum, or from red to violet on the same scale, would extend to 120 feet in length.

But this being supposed a rather longer scale than the world is as yet quite ready for, though demanding far more for certain parts of the Solar Spectrum, the original record has been reduced on subsequent working sheets to a 40 foot spectrum length. And as only the portions with very visible lines and linelets for the five bands of CH in air, are given,—this particular subject will yet be found in larger and fuller representation than it has probably ever enjoyed before, though packed away in four only of our plates.

## The Spectrum Plates Employed here, their Methods and Symbolism.

For the original observations and records on both the long 120 foot scale, and the first reduction to the forty-foot, I am answerable myself. But the drawing out of the final and finished plates, thirty-one in number for the whole paper, and all save three on the same exact 40 foot Wave-number per British inch scale, has been confided to Mr Thomas Heath, First Assistant in the Observatory; because his handling of the pen and pencil is finer than mine; and, under photo-lithographic treatment will give something like the perfection of copper-plate engraving, without its superior expense.

The said plates are intended moreover to serve more than the usual purpose of such data. For though it is customary, and was actually done by Messrs Angstrom and Thalen in their classical case, to give both a printed list of the numbers representing their micrometrical measures, and also an engraved, and

most beautifully engraved, map, or picture of the same—yet I have invariably found a mere list of printed numerical spectrum places, by whomsoever issued, to be but very little instructive,—without spending a lamentable amount of time over its interpretation, application and meaning on every occasion of using it; while it is also not a little expensive to print. Hence I have tried on this occasion to save the cost of figure printing, by throwing the whole burden of what is needed for final results, on the Plates alone.

Spectroscopic plates of some kind, on account of peculiar virtues of their own for such subjects, *must* be introduced in some shape, or to some degree. The following characteristic sentence occurs in a British Association Report for 1883, p. 123:—"Three such spectra have been photographed, *but without the aid of maps their peculiarities are not capable of description.*" Wherefore now, by keeping our plates sufficiently large, and with very clear and distinct scales, we may hope that they will not only preserve their own peculiar attribute of showing at a single glance the groupings and general bearings of multitudes of lines far better than any other known method,—but they will allow, on close examination and longer inquiry, the numerical places of any particular lines to be read off to nearly as minute a degree of exactitude, as the original observations were capable of giving.

This good quality would have been absolutely so with the 120 foot records; and if not quite so with the 40 foot size, that is why I specially request that Mr HEATH's drawings shall not be reduced any further, as no smaller scale can pretend either to do justice to the originals, see especially Plates LXXII. and LXXIII., or impart confidence to those who may use them. To which apology I have only now to add, that the following principles of representation have been strictly followed throughout all the plates of this series.

## PRINCIPLES OF SPECTRUM REPRESENTATION.

Rule 1. The representation is negative, in so far as it shows light by black; and darkness by white.

Rule 2. A vertical black line, whether thick or thin, tall or short, on the plate, represents, and is devoted to representing, nothing else than a true spectral line of light, seen and measured as such in the spectroscope, and is considered as precious a result of observation or discovery to the spectroscopist, as a real star is to the Astronomer.

Rule 3. Different degrees of *brightness* in the real lines of light in these gaseous spectra, where all lines are necessarily of an equal height,—are represented in the drawings, *approximately* by different thicknesses of the black lines employed there; and more *exactly*, by adding thereto the further method of different heights or depths of the lines so drawn.

Rule 4. When lines of light in the spectrum are so faint or ill-defined that they no longer give the appearance of solid or liquid light, and are no longer sharp and smooth-edged like knife blades, or stretched silver wires, but look more like faint, uncertain, granular, worsted threads,—the lines representing them on the plates are not drawn in full ink or with parallel sides, but of a conical shape, or in dots, or in wavy-lines, and in extreme cases with cross lines.

Rule 5. Faint broad bands in the spectrum, and its occasional portions of continuous spectrum light, are never indicated in these drawings by any kind or arrangement or succession of vertical lines, but by either horizontal, or oblique lines; and these may be crossed over and over again to produce the required degree of intensity in any case. For the lines of such shadings can evidently be never confounded with true spectral lines; which, being images of the slit of the spectroscope, must all be vertical and parallel, when the spectrum range is horizontal.

Rule 6. Shading by either inclined or horizontal lines being symbolic and abstract only; such lines may, for facility of execution, be of almost any degree of coarseness or width apart; provided only that the amount of ink contained in them shall, if symbolically supposed to be smeared up and down within the upper and lower limits of the horizontal spectrum strip,—indicate only a grey shade, not a full degree of blackness. And exceeding refinements of such shade or faint-light surfaces in the spectrum itself, may be indicated on the drawings by making the shading lines there cover more or less of height or depth in the spectrum strip, as already adopted for the easier representation of different degrees of brightness in the spectral *lines* alluded to under Rule 3.

## Drawings of the CH Spectrum in Blow-pipe Flame.

Now all the latter of these rules came into play at once with our first subject, or the blue-grey blow-pipe flame of coal-gas and air; for there is not light enough in it to give off any lines of real, liquid light, only haze of different degrees of rarefaction.

Considering indeed the proverbial faintness of the blue base of flame, as when a candle burns low and blue, it is rather surprising to find that so very small a portion of it as enters between the almost closed jaws of the spectroscope's slit, can yet be distinguished as made up into upwards of 400 parcels, separated one from the other always by different and definite spectrum place; and sometimes also by instantly recognisable features of physiognomy or gradated intensity.

Yet such is the case, for the plates now exhibited of the coal-gas and air blow-pipe spectrum (Plates XLVIII. to LI.), show 81 separate existences in the

Orange band, 94 in the Citron, 97 in the Green, 107 in the Blue, and 71 in the Violet. Their distribution in each band appearing thus—

| | | | | |
|---|---|---|---|---|
| Orange band—1st leader consists of lines | 2, | followed by linelets | 27 |
| 2nd | „ | 2, | „ | 14 |
| 3rd | „ | 2, | „ | 11 |
| 4th | „ | 2, | „ | 7 |
| 5th | „ | 2, | „ | 5 |
| 6th | „ | 1?, | „ | 6? |
| Citron band—1st | „ | 2, | „ | 25 |
| 2nd | „ | 2, | „ | 12 |
| 3rd | „ | 2, | „ | 9 |
| 4th | „ | 2, | „ | 7 |
| 5th | „ | 2, | „ | 31? |
| Green band—1st leader, "Green giant" | | 2, | „ | 41 |
| 2nd | lines consists of | 2, | „ | 11 |
| 3rd | „ | 2, | „ | 7 |
| 4th | „ | 1?, | „ | 7 |
| 5th | „ | 2?, | „ | 4 |
| 6th | „ | 1?, | „ | 17 |
| Blue band—1st | „ | 2, | „ | 21 |
| 2nd | „ | 2, | „ | 14 |
| 3rd | „ | 2, | „ | 12 |
| 4th | „ | 2?, | „ | 5 |
| 5th | „ | 2?, | „ | 55 |
| Violet band—Preliminary band has linelets . . . | | | | 20 |
| Subsequent and chief band contains lines and linelets of various kinds, certainly . . | | | | 51; |
| and probably many more; each being fainter and fainter in every successive repetition beyond. | | | | |

This is also probably the case with the linelets of the more refrangible ends of each of the earlier bands, for they are all vanishing series to that side. Hence to record more, or fewer of them, tells nothing new in the theory, but speaks only to the brightness of the optical images; and as I usually stopped, not when a definite end was arrived at, but when the linelets had become so faint and diffuse that it did not seem worth while to go on any longer,—other persons may succeed with better apparatus in chronicling more lines and linelets than I have done;—such gatherings however being always fainter than those now tabulated.

But even with them, the strain on the eye to measure their places micrometrically was often so great, that I was not unfrequently afraid I might be deceiving myself, and undoubtedly must have made many mistakes, particularly in setting the pointer between the close linelets, instead of upon one or other of them. Yet after completing the measurement of any band, there was found on the whole such a decided order, or law of increasing distance from linelet to

linelet, in proceeding from the red to the violet end, and of decreasing distance at the same time between the leading lines, or rather pairs of lines in each band,—as could not have arisen from mere accidental error, or blind fancy; and did seem to testify to a considerable portion of the interesting arrangements of Nature, in this branch of her handiworks, having been secured on this occasion in linear record.

If the leading lines too in each band, notwithstanding their faintness and haziness, have been represented by me as double, though single to all former observers, we may find strong confirmations thereof in our next subject, viz.,

## Advantages of Electric-Lighted Gas Vacuum Tubes.

These tubes are usually illumined for observation by that variety of electricity contained in the spark from an Induction coil, actuated by a Bichromate Galvanic battery. Such was the kind employed here, and was capable of giving sparks from 2 to 4 inches long in the open air: the size of the immersed portions of the plates being 4″·2 by 4″·6; and the number of cells 12, but only 6 of them having fresh exciting fluid each observing night. The coil was by Mr Apps, said to be a 6 inch spark coil if used with five quart-sized Bunsen, or Grove, cells. It was also furnished with a quantity, as well as an intensity, primary; one or other to be employed alternatively; but after many trials with little or no difference on spectra, I settled down to the intensity arrangement alone, and to carefully attending to the state of the spring brake; its freedom from oxidation; or from becoming self-soldered, and being in the best state of strain for illuminating sparks, without stopping dead.

Employing these sparks then on vacuum tubes, they may of course be expected to show higher temperature effects than mere blow-pipe flame. But they have other advantages over both that method of incandescence, and induction electric sparks in the open air, whether taken direct from the coil or with the interposition of a condenser, in the shape of "the jar discharge."

To illustrate the nature of these advantages for our particular purpose of Micrometrical measures of precision, I submit on Plate LII. four views of the salt lines ($D^1$ and $D^2$ of the Solar spectrum) rendered incandescent in as many different modes, and viewed under high dispersion.

No. 1 is the effect of burning a solution of Na (chloride of Sodium) on a small spiral of iron wire in the flame of a Bunsen burner of coal-gas and air, in the usual manner of all ordinary Spectroscopists. The effect will be seen to be broad, dull and hazy in the extreme; there is much continuous spectrum paling the lines, and the outer envelopes of vapour of the flame produce on each line an inversion of the direct action; or cause a black line to run down

the middle of each big bright line,—represented here by a white line on a broad black band, splitting it into two, but foggily and uncertainly.

This whole result is of course most unsatisfactory and untoward to sharp, micrometric bisection.

No. 2 exhibits the spark drawn from a solution of Na forming one of the poles, the other being a platinum wire. There is here no continuous spectrum, there is also something sharper and more intense than before in the picture which it gives of the D lines; but the abnormal central line down the middle of each standard line is repeated; and the whole is in a peculiar, crackly, continually exploding, condition, also opposed to very nice bisection.

No. 3 shows the same identical spark, but altered in quality by the introduction of a half gallon Leyden jar. The change is immense, the whole field being now filled with fervid light of the general air glow, also with certain hazy air-bands palpitating in their heated atmosphere, and which I have not attempted to show, while the D lines are still split through the middle and are hazy both inside and out. Finally,

No. 4 shows the D lines in an end-on vacuum tube. The field here is absolutely black about them; the D lines absolutely bright, sharp, compact, steady, well defined, and everything that a micrometrical observer could desire.

In a second tube with the D lines still as above, there were a few faint, low temperature, Hydrogen lines. These were just as sharp and steady as the Na lines, but being vastly fainter were exceedingly thin; so that, overlooking linear, in place of disc-point, figures, the whole field of view gave one the impression of gazing upward into illimitable stellar space, where one star differeth from another in glory, but all of them exist in the quietude of heaven, the calm of eternal peace and distance ineffable.

### A London Objection to my Testimony when using that Method.

The tube incandescence then is pre-eminently favourable for accurate micrometrical observations. But before I can expect to have my descriptions of what it has revealed to me listened to elsewhere, it will be necessary to meet openly an accusation lately printed against me by that very same British Association Committee whom I have already on other points alluded to most honourably for their ability, and presumed sense of justice. Yet the following is what appears at p. 12 of their Report for 1880, published in London, when speaking of certain of my observations at that date in vacuum tubes :—

" Professor Piazzi Smyth has however not filled his own tubes, and we must be careful not to attach too much value to the labels put on vacuum tubes by the glass-blower who has filled them."

Of course this a delicate insinuation that I *have* been trusting to such labels: if it is not also intended to indicate that he who fills his own tubes, as the actual writer of that sentence for behoof of the Committee of fifteen had done for himself, may take a very high place among the philosophers of the land. While any one who falls short of that particular tubular operation by the smallest item, no matter in what company, or under what system of friendly or scientific co-operation with others,—instantly pitches headlong down a social precipice, and may only bring up afterwards among glass-blowers.

Now it is perfectly true that I did not either make or fill my own tubes; and there has never been any secret about it; for I have from the first joyfully proclaimed who did that for me; and did it at last so well, that I could conscientiously recommend them elsewhere.

For as to the persons concerned, I have been very fortunate in interesting in this matter intellectually, several gentlemen of education, ability, and experience in both chemistry, scientific instrumentation, and business, viz., first, M. SALLERON, and then his successor M. DEMICHEL in Paris; next Mr LOUIS P. CASELLA, and then Mr CHARLES F. CASELLA in London; and finally I believe I may add, to name one deficient to none in persevering enthusiasm to conquer every chemical difficulty that arose in his path, though with little leisure and less of laboratory appointments, Mr W. H. SHARP of Messrs KEMP & Co. in this city.

With one or other of these gentlemen I have been in nearly continued correspondence for the last six years, discussing and trying experiments for the quality of the glass, size and shape of the tubes, materials of the electrodes, strength of sparks, arrangement and bore of capillary, as well as the methods of preparing the several gases, purifying them when made, removing occluded gases from the electrodes both before and during the filling, and then finally sealing. Sealing too not a single tube only, but a series at several stated and pre-determined steps of pressure.

But did I even then trust to either the necessary labels of some kind put on these tubes, or to the long descriptive letters also sent to me?

Certainly not, after the first few days of experience.

For my plan ever since then has invariably been, on receiving a batch of fresh tubes from any maker, to put them one by one into a testing apparatus; find out there what is in them by their stronger lines compared with the general literature of the subject, put my own labels on them, and perhaps send $\frac{3}{4}$ of the batch back to the maker for faults that had escaped him; and then would begin a correspondence to try and find out where, either in the making of the gas, or the steps of its purification, the fault originated, and how it might be avoided in a new set.

Again, even with tubes that have passed this examination, I have usually

reviewed a number of them before any night of final observation for the present paper, in order to find out if any changes with time and use were going on amongst them, and to ascertain more particularly for the service of the great spectroscope, which tube of them all, whatever its original label, was just then capable of showing a particular part of the spectrum of some specially required gas, with the greatest purity and the utmost vigour.

If this is still to be held up to public reprobation by London central and immovable scientific authority, as my "trusting to a label put on by a glass-blower,"—and because I did not fill my own tubes,—there is nothing left for me but to request the Royal Society, Edinburgh, to judge between us,—if I shall venture to set forth, before the close of this paper, how much more of the undoubted phenomena, of at least one particular gas I have succeeded in discovering, identifying, and micrometrically recording on an extended scale, than have any of those London and British Association gentlemen ever been able to observe in their tubes, although they filled them for themselves.

Resuming then, by this Society's leave, we come next to

## PART II.

### Citron, and Green, Bands of CH, in Vacuum Tubes.

After preliminary experiments with Alcohol, Marsh gas, Turpentine, Coal gas and Olefiant gas—I settled down to working chiefly the two last of these Carbo-hydrogen vapours or gases.

Of these gases much desired, pure CH spectrum, by electric light, but under atmospheric pressure,—MM. Angstrom and Thalen have given the two brightest bands, viz., the Citron and the Green, in their *Mesures Micrometriques.*

Those well-known bands make therein a very brilliant picture, especially as they are engraved in *ne plus ultra* style of both refinement and force; in the positive manner too, or with the lights white, on a field of black for darkness, and with an effect that Rembrandt might have envied.

The Swedish scientists do also there give a considerable indication of hazy, fluted linelets, continually getting closer, and brighter as they approach the least refrangible side of each band. But, strange to say, they have wholly omitted the vastly superior brilliancy of the leading *lines* in each band!

These strong *leading* lines are the first exact features which a beginner in spectroscopy makes out, to his great delight, when studying each CH Blow-pipe band; though at first sight, and with a too broad slit, said bands had probably appeared to him as only composed of smooth haze. And I can now further vouch, that those CH bands' leading lines, whether in blow-pipe or vacuum tube, remain equally conspicuous over the linelets, in all my subsequent

magnifyings up to a size fully 12 times larger than that of the Swedish Philosophers. These lines moreover in the vacuum tubes, are very distinctly double, and get wider and wider in their duplicities, though they decrease their whole distances of double from double, with every succeeding line.

There must therefore, in their omission, be an error in the work of those otherwise unexceptionable authorities; and it is pretty certainly owing in large part to the bad definition, or broad slit of the spectroscope there employed, as well as the greater practical difficulties in the positive mode of representing *bright-line* spectra. For the Upsala linelets are ultra hazy things, running one into the other and making only a confused and slightly undulating surface of luminous fog; culminating too soon, on the red-ward side, into the perfect light, or whiteness, of white paper. Whereas in my Vacuum tubes, far beyond the Blow-pipe's hazy separations already alluded to, the linelets, however faint, are thin and linear; and in some new tubes are capable of exquisite sharpness of definition, on an almost absolutely black field of view.

That however is not all that has to be noted with a very high Dispersion power; for after further working these tubes, the linelets became double, and after that even treble! Such a change however being always the beginning of a tube failing, or going altogether wrong: and was first testified to, as will be seen in Plate No. LIII., by the very superior optical power of a fine Grating which I had the honour of receiving from Professor ROWLAND, of Johns Hopkins University, Baltimore, U.S.; but corroborated afterwards only too abundantly by the older prismatic apparatus. Hence some advantage will be found, when comparing my different views of any of these CH bands, to note the name of the tube employed on the occasion, and the date of observation; a single day, of hard work, often showing great progress in the work of deterioration.

### ORANGE BAND OF CH; AND EFFECTS OF PRESSURE, IN VACUUM TUBES SO-CALLED.

For testing my own views of any other than the Citron and Green bands just disposed of,—we must fall back on the general map of the Upsala scientists, small though it be. But it is beautifully engraved; in the negative manner fortunately as to representing light by black; and professes to give the Orange, Citron, Green, Blue and Violet bands. Shading them, however, into striking relief by adding to others closely ruled *vertical* lines, which are a mere engraver's easy method of producing shade, and mean nothing, while they mislead much, in spectroscopy.

Comparing it, however, first of all with my own Index Map of CH in vacuum tubes (Plate LXXVII.)—what is the meaning of the immense force of the Orange band, and at the same time the dwindling down to a mere trace of

the Violet band in the Upsala Memoir,—so very differently to what occurs in that grand constant, viz., the Blow-pipe flame's spectrum of coal-gas and air.

In this last material nothing is easier on any occasion, and for any length of time, than to get all 5 bands to show; but the Orange band is always weak; and did therefore altogether escape some of the earlier observers.

In the tubes also, by electric light, the Orange band is far weaker than either the Citron, or the Green; but it has another difficulty to contend against there, of this nature,—

When the pressure of the CH gas is small, it is so very easily decomposed by the electric spark, that Hydrogen low-temperature lines are set free; and being nowhere stronger and more multitudinous than over the Orange region, they completely mask any residual traces that may remain of Orange CH, and much of the Citron CH, band, as well. But, as I have been finding with tubes specially prepared to that end, the decomposition becomes less and less with increasing density of the filling, until at several whole inches, instead of hundredths of an inch as with the old tubes,—Hydrogen lines nearly disappear, and CH bands like the blow-pipe's bands, so far as their range extends, are almost the only existences visible.

To get the CH Orange band, however, quite clear of those obstructions, is particularly difficult. Thus with coal-gas at 5 inches pressure, last year, every blow-pipe band was well seen, except the unfortunate Orange one; and so it was also this year with a fine tube of Olefiant gas prepared by Mr CASELLA at 2 inches pressure. But with another tube he had prepared at the same making, at 4 inches pressure,—such is the superiority of Olefiant, to Coal, gas for this purpose,—the long desired cynosure was reached at last. For in that tube's spectrum, while not a single low-temperature H line appeared, there was the Orange CH band as perfect in its symmetry of lines and linelets as anything could well be imagined, and as I have never seen it written yet.

There were to be counted in it 5 leading lines very bright and distinct and perhaps a sixth, all at successively smaller intervals in proceeding towards the violet: while between every pair of them, and in the interval beyond of greater refrangibility, were the linelets, in infinite thinness, sharpness, and definition; at first, or towards the red side, very close set, but continually increasing their distances apart, and preserving their inimitable Liliputian visibility, right up to the very beginning of the Citron band. This being a glorious extension of the vanishing side of the Orange band, far beyond anything ever seen with the blow-pipe, or even with tubes, when coal-gas is the filling medium.

Next, turning to the Citron band of CH (in the same 4 inch pressure Olefiant gas tube) its leading lines were vividly bright; its linelets also unprecedentedly clear, and never ceasing for a moment until, although continually

widening their distances from each other, and paling and thinning their light, but not losing their definition, they at last came right up to the Green band.

The Green band as a matter of course began with its "Green-giant" line in magnificent cue; then came closely packed, but well separated, sharply defined linelets; then the second leading line, and wider linelets, then the third leading line and after that the long expanding series of sharp linelets, which continued on, and on, and on, until the beginning of the distant Blue band was reached.

But shortly before that point was arrived at, a broad, faint, grey haze-cloud was passed. I had never seen anything like it, in that spectrum place before. What could it possibly be?

It turned out to be Glaucous Hydrogen. Not in the shape of the sharp and vividly bright line that it always shows in tubes at smaller pressures, but a mere amorphous bundle of Nebular haze.

Turning back then to the Red end of the spectrum, there, in the place of the usual Red Hydrogen line, was another broad cloud of faint haze, but of course red in colour.

This therefore was the reason why even the Orange band of CH, with its ultra thin and sharp linelets, was, for once, not sensibly interfered with by low-temperature H lines. For at that grand pressure of four mercurial inches on the Olefiant gas,—mere nascent Hydrogen could only exist, even with its strongest lines, as a sort of faint vapour, floating like a ghost over certain spectrum places; and all low temperature H lines being vastly fainter than its two just mentioned high temperature lines (Red, and Glaucous)—their resolution into similarly broad clouds, depressed their intensity of light to beneath the *minimum visibile* of any eye.

I spent perhaps half an hour noting these circumstances in the testing spectroscope which has 12° Dispersion A to H, and was planning how I would arrange the great spectroscope of 60° Dispersion, to take advantage of such an unprecedented view of the Orange band of CH,—when I fancied I saw a double line where lately there were only linelets; then a stronger line appeared between two of that band's leading lines: then another, and another. To my horror they began to look amazingly like low-temperature Hydrogen lines. Turning therefore to the places of the late nebulous clouds of Red H and Glaucous H, I actually saw them slowly gathering themselves together, and settling down as lines into their ancient places. While in half an hour more, Red H and Glaucous H were narrow and vivid exceedingly; while the whole band of lines and linelets of this poor, persecuted Orange CH was now hidden in a positive jungle of intrusive low-temperature H lines, of a most provoking degree of strength, brilliancy and number.

My hope then of presenting the Society with a large map of Orange CH, out of that tube, was gone for ever. Because, when decomposition, by spark

illumination, once begins in a CH tube, it never stops until all the H has freed itself from the trammels of connection with C (Carbon); and that element either falls inert, or if it can find any O, combines with that, and appears as CO, to the still further confusion of all CH bands.

At the same making where these two Olefiant gas tubes at 2″·0 and 4″·0 pressure were prepared, Mr CASELLA made for me another tube at only 0″·1 pressure. There was no O nor CO visible there, nor *any CH either;* nothing but the most brilliant set of lines of pure and simple H that were ever beheld, I should suppose, by mortal eye. In fact, at that low pressure, the first spark had decomposed the whole of that faint charge of Olefiant gas; its C was nowhere visible, but its H atoms were vibrating everywhere: and the only consolation I had for seeing nothing of the expected CH was, the apposite illustration that the whole case offered of a favourite idea of the late excellent Sir WILLIAM SIEMENS, whose loss we all deplore. His idea being, that the gases which, by combining under 800 inches pressure on the surface of the Sun, give out light and heat,—may, when excessively rarefied by removal into outer space, become decomposed or separated from each other under even the weakest physical influences; but are made ready in that way, on their return to the Sun, to give out light and heat by renewed combination under pressure, over again.

## BLUE AND VIOLET CH BANDS.

Of the Blue band of CH, I have little to say beyond what my readers will find out for themselves, on referring to Plate LIV., to my Index Map (Plate LXXVII.), and also to MM. ANGSTROM and THALEN'S Index Map, which *mutatis mutandis* is fairly enough compatible therewith.

But in the case of the Violet band, so large and bulky with me, so thin, small, and vanishing with them, there is a huge difference to be explained.

Now I should have already indicated that an exactly opposite difference in the case of the Orange band, seemed to be attributable there to the Swedish observations being made on gases at far greater pressure (probably the full atmospheric) than the densest fillings of any of my tubes; and the same reason, though with opposite effects, is apparently the acting cause at the opposite, or violet, end of the spectrum, of what we may note there. For with my own tubes, the denser the filling, the nearer did the Orange band come to the larger Swedish development of it,—yet the nearer also did the Violet band come to the Swedish depreciation of *it.* In fact in my densest tubes I have not only found the Violet band (the furthest visible one of the Coal-gas Blow-pipe series) an almost vanishing quantity,—but have proved an entire absence of a still more beautiful and powerful band beyond it—and which

ought otherwise (as well as another band between the blue and the violet) to be always seen at electric temperature, viz.,

### THE MARSH-VIOLET CH BAND.

This band was so-called, from Professor ALEXANDER HERSCHEL first finding it during some of these experiments in one of my tubes of Marsh gas; but it was already known to older spectroscopists who have used pure Oxygen, in place of atmospheric air, in their blow-pipes.

With stronger sparks too than my earlier ones, I have latterly found the band developed to more or less extent in every kind of CH gas;—and capable of coming out with far more force and picturesque luminosity that the previous Violet, or the ante-previous Indigo, band.

In short with its very pronounced leading lines, and then the expanding linelets after each of them, in such regular series,—this last and latest "Marsh Violet" CH band may be considered a most typical example of a CH band. It would also probably make a still more magnificent appearance in photography;—for, it is so far within the ultra violet of the spectrum range, as not to exhibit its full glories to the human eye, but is by just so much within the sphere of the impressibility of bromo-iodide of silver, focussed on by quartz lenses and prisms. My own plate of it therefore (No. LIV.) must be looked on as its *interim* presentation only.

### OF THE CHEMICAL INTERPRETATION OF THIS CH SPECTRUM.

Through all the variations I have been describing of this CH spectrum, however much more or less may have been visible at its one end, or the other, by reason of accompanying circumstances just explained,—no one known and recognised band in it, when tested by its sharp leading lines has been moved out of its spectrum place by the smallest, recognisable quantity. Hence it is one and the same spectrum throughout all the above intensity variations, and one so continually met with in this world, and in astronomy is so characteristic of the self-luminosity of comets, that it is most important to know what chemical science says as to its origination and nature.

I have been, thus far in the present paper, calling it the CH, or Carbo-Hydrogen, spectrum; but in London among the magnates of Chemistry and Spectroscopy, it has been declared to be the spectrum of C, or pure Carbon alone.

So, too, it was evidently very firmly held to be by them, a few years ago. For when I sent a paper on Auroral Spectroscopy to the Royal Astronomical Society in 1871 making use of the Candle-spectrum as a reference, and attributing it to CH in general, and Acetylene, or $C_2H_2$, in particular,—I have been

told, informally of course, where a secret meeting is concerned,—that a Royal Society Fellow on the Council of the R. A. S. informed that body that my chemistry was entirely wrong, and my paper was consequently rejected.

Now Carbon has long been known to be one of the most refractory substances under the Sun; though when exposed to the most terrible temperatures of Condensed Induction Electric sparks, it is forced at last, in the unanimous consent of all men, into incandescent vapour, and then gives out a totally different spectrum, to anything we have been describing, viz., one of a few isolated lines merely, see No. 3, Part I. of my Index Map (Plate LXXVII.). This therefore was termed by the London men, "Carbon spectrum No. 1;" while the spectrum we have been discussing, and which may be seen in the base of the weak flame of any little candle whose temperature is low indeed by comparison, was, with them, Carbon spectrum No. 2, or 3, or 4; on the then new presumption that a Chemical Element, instead of being confined to one spectrum alone, may have several.

The history of the origin, and metropolitan establishment, of this very contradictory conclusion for Carbon, is, that Dr ATTFIELD of London in 1862, presented a paper to the Royal Society there, which that body accepted and printed;—wherein he claimed to have seen the banded spectrum of the Blow-pipe flame of Coal-gas and air in every possible compound of Carbon with either H or any other gas; whence he decided, that the spectrum must be that of pure Carbon alone; however different it might be from the English Carbon spectrum No. 1. This decision therefore having been given forth under the auspices of the Royal Society, London, has remained the rule ever since in that region, however violently it conflicts with the Natural Philosophy of the case, and the Chemistry of Carbon in general.

Outside the London circle some very different ideas prevailed; but were ignored by the grand central authority there, until at last the progress of knowledge raised an earthquake in their midst, with effects which would have been far less disastrous, had the London magnates been previously only a little less exclusive. For thus, with a charming *naiveté* of confession, explains the British Association's Report of 1880,—

"On the whole it may be said that, from the publication of ATTFIELD's paper (1862) until the year 1875, every spectroscopist, whether he was a chemist or physicist, who had set to work to decide the question, came to the conclusion that the Candle-spectrum was a true spectrum of Carbon (*i.e.*, of C., not CH), and the question appeared to be settled."

Now I was not original in having, on the other hand, during that interval, upheld the Candle-spectrum to be one of CH, not of C; for I had learned it previously from my friend Professor SWAN, who, with his paper on the subject to this Society in 1856, is an older authority by many years on the Candle-

spectrum than any of the London gentlemen,—and yet, with myself, was pushed out of the pale of recognition through all that long period from 1862 to 1875 But what occurred in that latter year?

In 1875 was published the grand Memoir of MM. ANGSTROM and THALEN, wherein a very polite denial is given to the correctness of one of the most important of Dr ATTFIELD'S assertions, viz., that the candle-spectrum was an invariable accompaniment of a CO flame burning in the open air.*

Imperfect methods of preparing CO (Carbonic Oxide), argued M. THALEN, may easily allow CH gas to be present and give its spectrum;—but pure CO does not give it. So also I have found with my tube experiments,—for while some of M. DÉMICHEL'S very carefully prepared tubes of CO did not reveal a particle of any of the bands of the CH Blow-pipe flame,—certain other examples of CO by a London maker exhibited so much of the said bands, not too as a mere residual accidental impurity in the tubes, but as a something introduced *pari passu* by an erroneous chemistry in making the gas, *for it increased always with the pressure,* that I wrote at last for the particulars of the manufacture; and then discovered that the maker had been using a very weak and watery example of mere commercial Sulphuric Acid, instead of the most pure and anhydrous example that could be obtained.

The outcome therefore in 1875 of the opinions of such men as ANGSTROM and THALEN, could not be altogether repressed and repudiated even by the Royal Society, London. But that Society has since then had a severer trial to bear; for almost in the *et tu Brute* manner of the stricken Cæsar, they have had to read the later essays of Professors LIVEING and DEWAR, from the Cavendish Laboratory at Cambridge; and find therefrom, that those distinguished scientists have come to precisely MM. ANGSTROM and THALEN'S conclusion; viz., that the Candle-spectrum is a CH, not a C, spectrum; and that its uniformity through all varieties of CH chemicals, depends upon the formation of Acetylene, $C_2H_2$, in the course of the combustion or incandescence.

In short, the mental confusion that has now overtaken those who have ruled the London world of spectroscopy in this matter, so long,—is illustrated at the end of the British Association's Report upon it;—for it terminates with a disjointed, unnecessary and primitively simple statement of the spectrum places of the mere general beginning of the Orange, the Citron, and the Green bands of what may now be firmly called by every one, the CH spectrum.

Unnecessary was that proceeding of the Committee, because all men have

* From p. 14 of Messrs ANGSTROM and THALEN'S Memoir. "Quant à l'observation de M. ATTFIELD que l'oxyde de carbone donne le spectre ordinaire des carbures d'hydrogène, nous devons remarquer que cela ne s'accorde pas bien avec nos propres expériences.

"Dans un tube de Geissler, contenant de l'oxyde de carbone ou de l'acide carbonique, on peut certainement trouver des traces des spectres des carbures d'hydrogène, puisque le gas n'est jamais parfaitement sec."

been long since agreed on the said places, quite closely enough for identifying the phenomenon; and the Bezonian query of "C or CH" has never yet been attempted to be answered by referring to any doubt about exact Spectrum place.

## PART III.

### The CO Spectrum.

This CO spectrum should symmetrically arise in a combination of Oxygen with Carbon; just as CH represents Hydrogen joined to the same element; and accordingly vacuum tubes with a trace of Carbonic Oxide (CO) give the spectrum we have now to discuss, in a most marked manner and easily recognisable character,

In my former paper to this Society, I regret to say that I did, though with expressions of considerable reserve, allow for the time, with the English spectroscopists, that this spectrum might be one of pure Carbon, at a temperature between lamp-flame and that of the Condensed Induction spark. But I beg now to apologise for that error, to withdraw the name of "Tube Carbon spectrum,"—and to follow the teaching of Messrs Angstrom and Thalen, who consider it to be the spectrum of the compound gas CO, (Carbonic Oxide) and of that alone; for even if $CO_2$ (Carbonic Acid) be also in the tube, or even occupy it entirely, one charge of its Oxygen remains ineffective, and exactly the same visible spectrum, as that of CO alone, appears.

Now this CO spectrum, from the materials of its origination, is one of almost as extensive presence on the earth as CH; and has at first sight something of its appearance. Yet they are two opposing and antagonising principles at every step.

### Statical Differences.

In small spectroscopes the CO spectrum is so far like the CH, in that it is a spectrum of bands; but it has many more; so that while MM. Angstrom and Thalen have shown in their *Mesures Micrometriques* two only for CH, they show three for CO; and in their general Index Map they have represented 8 principal, 5 secondary, and some 16 very faint indications of tertiary bands, for CO; but 5 only for CH.

The 8 principal bands of CO reinforced by 2 bright ones of the secondary, are, from their spectrum places, of the following notable grades of colour—

| | |
|---|---|
| (1) Red, | (6) Green, |
| (2) Scarlet, | (7) Blue, |
| (3) Orange, | (8) Indigo, |
| (4) Yellow, | (9) Violet, and |
| (5) Citron, | (10) Ultra violet. |

All these have their brightest, hardest edges toward the red end of the spectrum, in so far agreeably with all the CH bands; while the Citron and Green of the CO bands, fall so nearly on the spectrum places of the similarly coloured Citron and Green CH bands, that beginners may sometimes confound them; or even imagine a physical connection and community between them.

A very little increase however of Dispersive power with Definition, will show that the CO bands have no leading lines in them, like those which are so prominent in CH bands. The CO bands in fact are made up of nothing but very uniform linelets, and therefore present a smoother, more enamelled looking, surface; and they are narrower than those of the other compound.

A far more certain difference however comes out on very highly increasing the spectroscope's powers; for then it will be found that every band of CO has its every linelet of a different construction, or we might almost say material, to any linelet of CH; and every arrangement of them is different also. This will appear perhaps most strikingly on comparing the Green band of either; but as we have already given that band of CH, we have only here to picture, describe and discuss the

## Green Band of CO.

In the Upsala micrometrical view this band is very short, and the linelets of which it is dimly indicated to be composed are coarser and wider apart than those of CH.

The shortness of the band, as given, merely arises from the circumstance, that at the point where it is cut off towards the violet side,—Green CH (when that is simultaneously present, owing to faulty chemical preparation of CO, or otherwise) comes in, and one band, after that, overlying the other produces confusion. The Upsala philosophers therefore did well, in picturing for green CO by itself, only that little bit of its Green band by whose small breadth it comes out from behind the bright beginning of Green CH; forming in that way a tiny peninsula of perfectly pure Green CO illumination, which is already somewhat celebrated in spectroscopic story.

A few years ago this peninsula was thought so very narrow, or minute, a quantity, that it was proposed as a test, much better than the Micrometer measures of that day, to settle whether the carbonaceous spectra of Comets belonged to CH or CO.

In MM. Angstrom and Thalen's Index Map, the said little bit measures 0·23 of an inch broad, and the shading expended upon it does not claim to be anything more than engraver's ornament.

In the larger plate of their *Mesures Micrometriques* the CO peninsula of Green measures 1·4 inches across, and shows 14 indistinct or rounded corrugations, or "flutings" of surface.

In my own finally reduced plates it measures 4·3 inches across, and shows no less than 44 distinct and positive lines.

But in the original records of my spectroscope, and which alone I would desire to refer to now (see Plate LXXVIII.), the breadth of the peninsula is upwards of 26·4 inches; and though it shows only the same 44 lines just alluded to,—yet it gives them with a force, a character and an effect that can be attained on no smaller scale; and was the practical mean by which many of them were first discovered to exist.

Though speaking of these 44 luminous existences as lines, yet it is to be remembered that they are nothing but the linelets composing what appears in smaller instruments a smooth shaded band; and with my largest spectroscope, it was the most extraordinary thing to contemplate the broad fields of absolute blackness that separated each one of these vivid, hard, sharp-edged, well-defined lines from its nearest neighbour on either side.

Nor was it less instructive to use a tube containing both CH and CO; and then compare in the same field of view these two opposing principles, as it were, of the Physical world. The unoxidised against the oxidised; the fuel still to burn, against the refuse of fuel long since burnt; this latter the condition of the whole surface of our planet, rocks and water alike, excepting only its coal beds and a little amount of gold and other unoxidisable metals.

The green CH band comes in (as will be very clearly seen in Plate LVIII.) just on the right of the green peninsula of pure CO; and with its doubled Green-Giant line of CH, shines gloriously enough, but yet with a suspicion of haziness along its edges; while its closely packed following CH linelets, though sometimes exquisitely defined, have something of a gossamer weakness and transparency of look. They are like mere filaments of silk, or spider lines at the best; and if doubles are seen amongst them occasionally, it arises probably from a process of decomposition having set in, or Hydrogen freeing itself from all earthly contamination; a liliputian curiosity in a vacuum tube, but the chief acting agent in the mighty red prominences of our Sun, and in the terrific conflagrations of so called new, or temporary, stars.

With CO on the other hand, and its CO linelets, which are the best defined and hardest of diamond-like lines in structure,—if you see them once, you see them always; fixed like the rocks; or even growing in their places; for when once Oxygen has got hold of any Carbon, all the further actions of the illuminating spark seem only to enable it to go on taking an equally firm hold of all the rest of the carbon that may be within its reach.

In fact, while the usual mode of failing for any CH tube by powerful sparking is to end in its showing nothing but H lines, so for tubes containing any compound of Oxygen, it is to finish by showing nothing but the CO spectrum. And if it has been said, that in the event of a solar conflagration

of this world, nothing of its solid material would be left, except atoms and molecules vibrating in the intense light and heat, we may be pretty sure that while Hydrogen would be dancing like the fire-fiend above the scene of destruction, the more stolid CO would dominate beneath.

## Its Numerical Explanation.

But would such a reproduction of Nebular haze bring back the chaos, the confusion, of the Greeks; or would it be an entrance into a superior realm of law and order, in number, weight, and measure?

Let the 44 lines in this Green peninsula of CO, now first rescued from the very bad definition, uniform haze, and contracted views of the old observers,—answer for themselves.

There are evidently amongst them, on the grand 26· inch scale, lines thick, and lines thin; lines single, and double, and triple; some expanding their distances apart in the direction of the violet, and others towards the red; there are places of unseemly crowding together of many lines, and other spaces which are comparatively bare,—in short, a careless viewer would pronounce at once for confusion. But having fortunately sent one of the original, and raw, but large sized instrumental records to my friend Professor Alexander S. Herschel,—he was enabled by his experienced study of such phenomena to return in three days a demonstration, that each of those 44 lines was a necessary step in a remarkable system of physical numeration, proceeding in two rows of simple arithmetical progression, one over, but slightly advanced upon, the other; not accidently or discordantly,—but so as to set forth the unit, the quinary, the decimal, and even the quinquagesimal standard of what may be now termed the CO system of linear construction.

The success of this numerical demonstration, this extraction of scientifically ordered simplicity out of at first sight extreme complexity, may be quickly judged of by reference to the large Plate No. LXXVIII. prepared especially to show it; but more completely still, by reading Prof. A. S. Herschel's letters in Appendices Nos. I. and II. Their account is happily so complete, and so independent, as to leave nothing further for me to remark upon here, except observationally; for theory in this case has given pretty certain indications that 8 lines out of the 44 which I have set down as single, are really doubles; but far closer than anything which I have yet been able to resolve. These cases must therefore be left to future observers, a test for their instruments to come; and a still further proof we may expect, when it does come, of the exact geometrical foundations of the very smallest components of the ultimate materials of Nature.

## Remaining Bands of CO.

Of the Red, the Scarlet, the Orange, the Yellow, and the Citron bands of CO below that Green band which we have just been discussing; and of the Blue, the Indigo, and the Violet bands above the Green,—and which are all pictured in the Plates Nos. LVIII. and LIX.,—their linelets seem to have somewhat similar characteristics on the whole to those of the Green band,—but with compound variations,—not yet fully made out by observation. Nor perhaps very soon likely to be much further elucidated, because

(1) The dispersion of my present Prisms below the Green is too small;

(2) Above the Green the definition is not sufficiently good;

(3) Towards either end of the Spectrum the illumination of my existing sparking apparatus is not sufficiently bright; and

(4) It is very difficult to get those bands perfectly free from impurities of CH, H, and other gases.

I will therefore at present proceed to a provisional termination of the CO subject, by means of a few words on some general characteristics of that compound gas in vacuum tubes.

A small pressure of the gas, say 0·25 inch, seems to be most suitable for securing a maximum of brilliancy conjoined to stability. For higher pressures, say 1 inch, 2·5, 5·0, or 12·5 inches, simply show the same spectrum, but fainter and fainter as the pressure is greater; while lower pressures, say 0·1 inch or under that, though exceedingly brilliant for a time, are very apt to get their tubes overheated and loosened at their electrodes with loss of illuminating power altogether. To prevent this catastrophe, the electrode ends of the tubes, whether with platinum wires as usual passing through them, or coated only with a film of silver outside, have been made to dip into vulcanite insulated basins of water, and receive their electric charge from thence; but the illumination was never at its best in that manner, the whole apparatus sometimes became inconveniently charged; and with the silver coated tubes, the glass was actually perforated sooner or later. Some of the best exhibitions, however, of the CO spectrum, have been the unintended ones; as of tubes prepared with Oxygen alone; and showing at first the Oxygen spectrum, but that changing during use into CO; and always more and more quickly or inevitably, the weaker the pressure at which the Oxygen had been sealed in.

Whence comes the C for this transformation of O into CO?

Some persons have suggested, from the use of a coal-gas, in place of a hydrogen, blow-pipe in working the glass; and an extraordinary hypothesis has been recently started in Germany, of Si being convertible into C in vacuum tubes.*

* The following note has been furnished to me:—"Herr Wessendonk prepared Siliceous gas with most scrupulous care and purity, without being able to obtain a trace of Silica lines, only CO bands over and over again, and more and more brilliant the purer the gas he used. *Silica* could never be found,

But my own idea is still, that it may be owing to the electric spark's power of convecting C along its wires; and then, not merely because such wires are usually coated along their whole length with an easily melted material so rich in C as Gutta Percha,—but because the Induction coil itself is, throughout its chief bulk, little but a huge mass of soft C; and the rolled up insulated wires inside it, make it a perfect ganglion for accumulating all possible transportable atoms of that element.

Some small spectroscopic evidence in this direction too, is already in print; as thus, plate i. of M. LECOCQ DE BOISBAUDRAN'S admirable book *Spectres Lumineux* gives two pictures of the electric spark in open air; one near the positive, and the other near the negative, Pole. They both of them exhibit chiefly the well-known low-temperature Nitrogen bands; but the latter, or Negative Pole's end, has a glorious distinction from the Positive's, in this, that it has also a very strong violet line, the *a*, or chief of the whole display, which does not belong to the simple Nitrogen's or to the Air's low-temperature spectrum at all; nor to their high-temperature spectrum either.

To what then does it belong?

According to my earlier and perfectly independent "gaseous spectra" paper to this Society in 1880, it is the characteristic line of Cyanogen, or Carbon combined with Nitrogen, the chief constituent of our atmospheric air. Carbon vapour then added to the spark which is producing the Nitrogen spectrum in the open air, can hardly but produce this Cyanogen leading line; and such Carbon can be obtained by the electric current from nothing so readily as the gutta-percha, vulcanite, and waxed, or resined-paper interstitions, which form so notable a portion of every Induction coil.

But as I had an opportunity of setting forth something of this view in *Nature* journal last year, assisted by a woodcut of the spectra,—I here close this part of the present paper on the two compound and opposed gases, CH and CO; in order to proceed to the next part treating of the three elemental gases H, O, and N.

## PART IV.

### THE THREE ELEMENTAL GASES, H, O, AND N.

#### SUBJECT 1.—H OR HYDROGEN.

There is little trouble in procuring good H tubes; and they are such excellent illuminators as to get the better of all ordinary impurities, espe-

in any quantity to speak of; so it could not have come out of the glass. $SiH_2$ and $SiFl_2$ were used (very easily prepared pure). CO was the only result he could possibly obtain. That, and always that."

cially with time and use; and show at last nothing but the Hydrogen tube-spectrum with brilliancy and certainty at any pressures between 0·1 and 0·5 inch.

One particular impurity, however, has to be guarded against; for its lines though few, are strong, viz., Mercury,—whose vapour always has a chance of entering, in connection with the Sprengel air-pumps now so generally used in the exhausting operations. To this end therefore some tubes specially containing Mercury have been made for me in Edinburgh by Mr W. H. SHARP (of KEMP & Co.), and have furnished the Mercury low-temperature spectrum which appears as No. 13 in the second division of my Index Map; and will enable any one with great ease to eliminate Mercury, from the H, lines; especially if they try it at various lamp temperatures.

But not a great deal has yet been written on the tube, or "low electric temperature," H spectrum, though every one knows about the 4 grand lines in its high-temperature spectrum, and which reappear in the tubes, together with all their low-temperature lines. MM. ANGSTROM and THALEN, for instance, are silent on the subject in 1875; and still more remarkably Hydrogen does not figure in the otherwise very comprehensive list of gaseous spectra treated of by the British Association's Committee's Report of 1880.

Fortunately these low-temperature Hydrogen lines attracted the attention several years ago of the *savants* of the Imperial Central Observatory of Russia at Pulkowa; and Dr HASSELBERG, their chief spectroscopist (a former pupil too of M. ANGSTROM), entered into the subject with intense enthusiasm. He had begun with other gases, but soon alighted, as I had done in my paper of 1880, on the existence of low-temperature lines, as an addition to the well-known high temperature spectrum of 4 lines only for Hydrogen. He found them too so invariably in any and every mode of preparing Hydrogen gas, that he concluded they must belong to it alone, and under such impression prepared a map of them about 18 inches long, with three of the four great lines introduced amongst them.

But that size of map he afterwards considered did by no means do justice to the richness of this H spectrum, wherefore he laboured again with new prisms; and in the course of last year, published with the Imperial Academy of St Petersburg, a new map of Hydrogen "tube" lines by simple electric spark, or the many low-temperature + the few high-temperature lines; the map having a length altogether of nearly 90 inches from the Red to near the Violet line.

This last map of Dr HASSELBERG'S is a very grand work as compared to anything yet published, either on the H, or indeed any other, gaseous spectrum; and it will doubtless be long regarded as a high authority for the absolute spectrum place of the lines which it contains.

Hardly so, however, for either the number or minute physiognomy of most of its lines; for whereas the Doctor begins the low-temperature H lines far within, or above, the great Red Hydrogen or C line of the Sun,—I have found them commence far without, or below, Red Hydrogen; continually increasing too in brightness as they pass that line, and at length join on to Dr HASSELBERG's earliest lines, which are with me very bright. And then again, his scale of 90 inches must necessarily fall lamentably short of a 480 inch spectrum, when it is a question of detecting a close, double, or triple, hitherto recorded as single only.

This indeed by itself might have been got over, or apologised for; but unhappily the laborious author has allowed his engraver to exert his own taste in doubling and frebling the chief part of his principal lines, and even making a banded group out of the grandly single line Red H, in a manner, and to a degree which must entirely mislead the spectroscopic searcher after micrometrical truth.

Now my own original measures of this spectrum, though they cannot pretend to compete with his for accuracy of absolute-spectrum place, are on such a scale that from the earliest Red to the Hydrogen, Violet occupies as I have already mentioned, a continued length of 120 feet. So that if, in this grand hall, you imagine the spectrum strip to begin over the President's Chair, and extend thence continually towards the right, the red and scarlet would reach the end of that wall, the orange would cross that end of the room, the yellow, the citron, the green and the glaucous would occupy all the other long side of the room, the blue would cross its further end, and the indigo, the violet, and the ultra violet would come back and overlap very nearly the beginning of the spectrum's scroll right over the President's head.

Along with that immense length, truly immense considering it is merely a magnification of a slit about $\frac{1}{300}$ of an inch wide,—you would see nothing of bands of CO with their orderly, closely set regiments of linelets, nothing of the leading lines and fainter linelets of CH,—but only lines and lines and lines again, free, easy and distinct of H. There are some 1625 of them absolutely recorded at the instrument; generally they are brilliant, well-defined, showy lines; nowhere very closely packed, but forming all the way along an independent kind of open groups, which have perhaps a certain kind of family resemblance among themselves, but with never any precise repetition between one group and another, either of its strongest single lines, or the occasionally exquisite doubles or trebles which try all the powers of the best spectroscopes yet made to resolve them. In short Hydrogen, in between the positions of its four grand high temperature lines, shows in these almost endless low temperature lines of the tubes, nothing but a saltatory sort of movement, such as an ariel sprite might indulge in, and such as does typify the

taste or the instinct of Hydrogen to shake itself loose from all terrestrial matter, and rise above all the other elements the lightest and most ethereal of them all.

But my apparatus is still so far from describing all that Hydrogen has to show, and which future observers may discover,—one does not know how soon,—that I make no attempt in the present state of the question to try to develop the kind of order on which its arrangements are founded;—but would beg leave to call attention, by its means, to a general feature touching definition in all bright-lines pectra, viz., excepting some of the fainter lines in the ultra Red, the definition of Hydrogen lines is inimitably fine and sharp through the red, scarlet, orange, yellow, citron, and green until we come near the blue, where a little falling off sensibly occurs. In the further Blue and the Indigo the defalcation increases; and in the Violet becomes unbearably offensive; so that what should be a sharp line of light, becomes more like a dull, broadened, or diffuse woollen cord or hazy band.

Is this change which thus supervenes on approaching the Violet end of the spectrum, a fault of the instrument; or a quality of Nature; or a failure of the human eye?

Not a fault of the particular instrument built up by me in rather rough and economical fashion, because I have met the same principle of effect in every spectroscope I have looked through,—even including that charming instrument, the Cooke-Monckhoven spectroscope of Professor TAIT's Natural Philosophy Laboratory,—a spectroscope whose every adjustment is carried out to perfection, and where nothing seems to have been omitted or neglected.

Nor is it a necessary, and innate quality of Nature; for exquisitely defined spectrum lines in both the Violet and ultra Violet regions are said to be obtainable, and have I believe often been obtained, though not by me, in the medium of Photography.

Then the failure must arise in the eye. Yes, in the human eye and its total inability to distinguish between Violet as it is in the spectrum, and every other so-called Violet colour under the Sun. For these, so far as I have yet examined, whether in chemical solids, or fluids, flowers or stained glass, are nothing but a mixture of blue and red; and are allocated to a totally different mean spectrum place than that of violet, by the more than man's discriminating power of either the prism, or a diffraction grating.

In fact, except for the purpose of establishing a sort of border neutral territory, where eye-results may be compared with the blackened imprints on bromo-iodide of silver, so extra sensitive to violet light,—no eye observations should be trusted for minute features and full effects, much beyond Glaucous Hydrogen,—for there Photography can be brought in with advantage, and probably will be, before long for everything, by those eminent scientists who

have of late employed that method in their own special researches, but usually on a far too miniature scale to satisfy present requirements.

## Subject 2.—O or Oxgyen.

With this gas comes in a change; a relief perhaps to many persons after the growing complexities of other spectra.

So far at least as the O spectrum has yet been seen and published in vacuum tubes, it is simplicity itself; and though called "the compound-line" Spectrum of Oxygen, that name was given to it merely in deference to a theoretrical idea, in accordance with which the lines *ought* to have been compound; or at all events totally dissimilar to what has been termed, by way of pre-eminence, "the line" spectrum of Oxygen;—because that is what results from the high temperature of the jar, or condensed discharge of induction sparks,—in contradistinction to the low temperature, or direct discharge, of the simple spark, which we are now dealing with.

Of this low temperature, "called" compound-line, Spectrum of Oxygen then it is, that the British Association's Report speaks, when it declares it to consist of four lines only; one in the Red (or Orange rather), two in the Green (or rather one in the Citron and one in the Green), and one in the Blue (or rather between the Indigo and the Violet); but the spectrum places of all four have been accurately measured in Wave-lengths, so that they can be easily identified by any one.

A gaseous emission spectrum then, consisting of four widely apart lines only, must surely be as simple as any one could desire; and the statement is founded on very high authority, viz., a paper by one of the British Association's Committee, printed by the Royal Society, London, in 1879. The author of it too, —being one who not only "fills his own gas-vacuum tubes," but who launched the depreciating accusation against me that I did not perform that operation for myself (pp. 11 and 12),—I shall hardly be allowed, by either of those two great English Associations to put forth any accounts of more lines than their four; and yet, if my mode of arriving at more than four had been dependent on my filling my own tubes,—would there not have been a chance of my being compared to that publie lecturer who, about half a century ago, in London, undertook, in defiance of the doctors, to drink off half an ounce of Prussic Acid, ot deadly strength according to the Pharmacopeia, but stipulated that he must prepare the fluid himself!

Before relating however what I have found, and how; viz., by open methods which should bring out the same result in whatever part of the world they are performed, and have brought out the same in the hands of both French and English workers;—there is something more to be precisionised in the Royal

Society's printed paper alluded to. The letterpress thereof certainly speaks of four lines only, and gives the places only of 4, in figures; but in the map accompanying them they are made into 8; viz., each line of the four is made a double line; two, much more distinctly so than the other two. It is not for me to pronounce on the accomplished fact of the Society's thus doubling the number of lines in a very scantily furnished spectrum; and making the original single lines of observation conform more nearly to the theory they publish, by representing them "compound" to the extent of doubling each one,—but it is absolutely necessary for truth's sake to warn all into whose hands the Philosophical Transactions may come, of the absolute falsity of the (London) Royal Society's Oxygen spectrum plate, in that respect.

The talented author of the paper, moreover, has never claimed to have seen more than four single lines, placed as described; has made an immense number of most admirable experiments to assure himself that they belong to pure Oxygen, and not to any accompanying impurity,—and that there is nothing else in the O spectrum of equal visibility. That degree of visibility however, being something very small; for Oxygen gas is what is generally known, as a bad illuminator, in all vacuum tubes.

There then, with only *four* truly observed lines, the tube spectrum of Oxygen might have remained, had I not in 1879, independently of the late energetic Dr VAN MONCKHOVEN, both struck, and worked out, the idea of using vacuum tubes end-on, in place of transversely to their capillary part, as others seem to have done universally before that time; some of those earlier observers even using the tube's upright line of light, in place of the slit of a spectroscope proper. But with the new end-on vacuum tubes, and equally when they were made for me in Paris, or in London, I immediately, through the greater brightness of their light, saw the presence of many fainter features constant in, or evidently belonging to, the O Spectrum of the four lines.

First, for instance, I found that three, out of the four, primitive lines were, each of them, a triple. Each triple a long way from its nearest neighbour, but of precisely similar build; and I have since then discovered three other such triples, one of them further away towards the Red, than the longer known Orange one; and two others further towards the Blue, than the older Green one.

They make moreover a remarkably connected, though wide apart, and only faintly luminous system altogether, extending through so great a range of the Spectrum as from Red to Glaucous; for the six triples are arranged in three pairs, whereof the mean place of the third pair is from the mean place of the second pair, close on half the distance that the mean place of the second is from the mean place of the first; while at the same time the much smaller distance apart of the sixth triple from the fifth is just about half that of the

fourth triple from the third; and that is again about half that of the second triple from the first. And finally, to carry the principle still further into details, but these details supposed to be more nearly eternal than worlds, and suns, and stars,—in each of the six triples the third line is about half the brightness of the second, and at half the distance from it, that the second line is from the first line.

Indeed the characteristics of an Oxygen triplet are so peculiar, and so closely adhered to in every instance, that I have been able in some tubes swarming with lines of impurities to pick out an Oxygen triplet, as easily as one would distinguish in a crowd of civilians, a soldier with cross-belts and scarlet coat.

Although then there is so little show of general light in a pure Oxygen tube, geometrical order is preserved there amongst such lines as it does show, most rigidly. So that while Hydrogen, with its multitudinous, brilliant, varied lines dancing or vibrating through the whole length of the spectrum, may be likened to a big, curly-haired, Newfoundland dog, bounding about and barking at its own free will,—Oxygen is a Bull dog which, without any show, runs straight to his quarry and holds him fast with an iron grip.

This view, moreover, trifling as it may appear, comes out more notably still, when we attend to the many single lines which there are, after all, in the Oxygen spectrum, and are shown both in my Index Map, and the larger plates, Nos. LXVI., LXVII., LXVIII., and LXIX. For, in spite of its faintness of light, Oxygen in the spectrum actually outflanks every other gas. That is to say, it begins with a very well marked and sharply defined line, further away into the ultra-red than any line, band, or haze of any known elemental gas. This same lowest line too of the O tubes appears to be identical with the most red-ward line in the jar-discharge in the open air, as described in my recent paper to this Society on BREWSTER's Solar line Y.

### SUBJECT 3.—N OR NITROGEN.

This is the last gas I have observed on the present occasion, and its spectrum is in many respects the most mysterious, and most multitudinously lined of all, when seen with great dispersive power; for otherwise, it is an affair of hazy bands alone.

Just as it was with O, so here, *mutatis mutandis* is it with N, that a condensed induction spark, or jar-discharge, discloses the high-temperature, or line, spectrum of the gas; and if the two gases be mixed together as they are in the atmosphere, the same discharge shows the line spectra of both gases overlying or multiplying each other; as may be seen in the upper portions of of the Index Map; forming hazy lines when in a dense, sharper lines in a

rarefied, medium; but evidently the same linear spectrum in each case, and of but a few, say a score or two, lines even at brightest.*

With the simple or direct spark on the contrary in the open air, those two spectra vanish, and are replaced by other two, perfectly different; whereof, as just described, that of O is barely visible to moderate power, even in its isolated compound triples or the stronger of its single lines lately discovered; while N is heavily conspicuous all along the spectrum in the shape of a closely packed arrangement of numerous, narrow bands. In a vacuum tube of N alone this arrangement is still more brilliant, is generally known as "the band spectrum of N," and "is one of the most beautiful," says the British Association Report, "which can be observed."

The best map of it I have yet seen is that in ANGSTRÖM and THALEN's paper of 1875; a map about 27 inches long, and exquisitely engraved; *i.e.*, so far as engraver's work alone is concerned, for the vertical lines wherewith the bands are shaded are engraver's ornament only, and have no pretension to representing lines seen by the observer. But with this reservation accepted, the map effectively reproduces all that was known of the spectrum until 1880; when Prof. ALEX. S. HERSCHEL communicated to this Society some notable extensions of the spectrum into the ultra red, which he had just then made with my Spectroscope as it then was, or merely in a pretty good condition.

His whole conclusion I believe was, that he could identify many more of the narrow bands of N, in that lower region, far beyond or outside the place where the first of THALEN's pictured bands begin. And he could even trace them up to a place where a triplet of sharp lines shot up, and seemed to form a sort of fountain head, whence had flowed down the continued stream of Nitrogen cross-bands all through the Red, the Orange, the Yellow, and the Green of that spectrum.

With my present improved instrument, and several new and exquisitely pure tubes of N prepared for me by both M. DEMICHEL in Paris, and Mr CASELLA in London, at various pressures between 1·0″ and 2·5″,—I have been enabled somewhat to modify the above view, as thus,—

(1) The band spectrum of Nitrogen, even in those brilliant colour regions just cited, is by no means one uninterrupted series of similar bands,—but is a succession of four large groups of bands; each group bringing in with it slight variations on the preceding one, and separated from its neighbour group on either side, by a tolerably distinct breadth of 2 or 3 bands of weaker action.

(2) THALEN's first band, though no longer to be regarded as the first band or beginning of the N spectrum, is yet the first band of its own, or the Red, group; which we may therefore worthily denominate THALEN's group.

* The manner in which the Red Hydrogen line comes into that Spectrum, is very striking, and I have not yet seen a good reason given for it.

(3) Outside and far away into the ultra-red, more N bands do extend, as Prof. HERSCHEL saw; but they form a group of their own, beginning in faintness far beyond Prof. HERSCHEL'S triplet of lines, or anything that he saw; rising in intensity of light and markedness of physiognomy as they pass that triple of his, and finally subsiding again very materially before they join, but unsymmetrically, the first band of the THALEN group; for which features please to examine, first the Index Map, and afterwards Plates Nos. LXX. and LXXI.

(4) Prof. HERSCHEL'S triplet of lines is however a very interesting existency, with nothing else like it through all the rest of the N spectrum, and with these two following features in addition,—

(*a*) It is shown only, so far as I can make out, in N tubes at very small pressures, say under 0·1″; for brighter tubes as to the bands but at greater pressures, say 0·5″ to 2·5″ show nothing of it.

(*b*) This triplet of lines, so anamolous in the tube, and unsymmetrically placed as to the bands of the ultra-red group which pass in front of it,—is nevertheless owing to the N gas; for it appears to be identical with the triplet of lines which I discovered last summer in the jar discharge in the open air. The one line seen on that occasion outside the triple, has since then been identified with Oxygen; but the triple having no resemblance to anything in that spectrum, can hardly be of any other than N material, and may be deservedly noted as HERSCHEL'S N triple.

If the large Plates of the N spectrum, Nos. LXXI., LXXII., and LXXIII., as observed by myself be now examined, it will be seen that THALEN'S Red series of bands opens a more brilliant portion of this spectrum; and one which, in and after its third band, effloresces into almost an infinity of the closest and most exquisitely defined lines and linelets that were ever packed into a telescopic field of view. Nor were they all revealed even then, for amongst them seemed to be doubles, or other multiples so exceedingly close that they passed the power of my spectroscope, even at the best, to resolve with certainty; and how many degrees further their intricate refinements of structure extend through the residual haze, of which a little still appears,—it is dangerous to speculate.

Had it not been for the method I elaborated of recording any number of micrometrical places of lines consecutively, and without taking the eye away from the eye-piece,—the attempt to note the exact place of each and every one of such legions of lines in the usual micrometrical manner, would have been hopeless; for at the average rate of closeness of those which I could separate, there are probably 4000 in the first half of the N spectrum alone.

The brightest example of the N tubes, viz., one at 0·1″ pressure, broke down, I regret to say, early in the work, or when I was using it near the D

region; the rest was therefore recorded by means of a 0·5″ pressure tube, compared occasionally with 1·0″ and 2·5″ pressure tubes.

Of the gradual swellings and subsidences of brightness in each of the four long groups of bands (the red, the orange, the yellow, and the green), and the minute variations introduced into the composition and settings of the linelets forming all the several bands of one group, compared with all those of another group,—the Plates Nos. LXXI. to LXXIV. will give a better and quicker idea than verbal description. And they will also indicate well the immense change which comes on in the Glaucous region, making the rest of the Nitrogen spectrum, through the Blue and Violet an utter contrast to its earlier appearance from ultra Red to Green.

This difference is marked strongly in ANGSTROM and THALEN'S map, in so far as those classic authors represent the Blue and Violet bands much broader than the Red and Yellow. But they have wholly missed the club-like, or fascicular, groups of lines with which each such Blue or Violet band commences.

I have had therefore to alter my Index Map considerably from theirs, in order to represent this most innate and valuable distinction, as it appears to me, of blue N, from blue CO, bands when in close neighbourhood. And the minuter construction of these clubs of lines may be made out pretty well in the larger plates of N, as Plates LXXV. and LXXVI., notwithstanding the characteristic bad definition of any and all spectral lines in the Blue and Violet.

There is another peculiarity, however, well worthy of note in these more refrangible and very broad bands; viz., that there is another class of bands with sharper beginnings mixed up with them; and these additional, or smaller featured bands (unnoticed I believe as yet by other spectroscopists), are more constantly and certainly seen in tubes prepared for N, than those prepared for $N_2O$, or Nitrous Oxide. Or, in other words, the $N_2O$ Spectrum is simpler than that of N; though the chemical notation as it stands now, is more complicated.

But I have no maps of the Nitrous Oxide spectrum to show, on account of all the $N_2O$ tubes, after a preliminary eye survey had been taken, having gone wrong spontaneously, while I was observing those of N; and I had no more funds for further tube making.

My present task therefore is finished, save a few words, or perhaps mere conjectures respecting the possible chemical origin of the spectra just described for

THE THREE ELEMENTAL GASES, H, O, AND N.

## PART V.

### Concluding Notes on the Elemental Gases, H, O, and N.

If in the earlier part of this paper, we found it expedient to admit that the two separate spectra there described were the spectra in each case of a compound Gas, viz.; the one of CH and the other of CO; and to some degree because the high-temperature or jar discharge gave a totally different spectrum to C alone; is there not something rather similar to be said touching the spectra we have just been describing for H, O, and N, though they are simple and elementary gases according to the Chemists?

There is at least in so far, that if we try said reputed simple gases, not with the weak direct spark which we have been using all along, but with the intensified or jar discharge, there is introduced for each of them a totally different spectrum from that which we have been describing. But why, in that case, are our tube spectra of those gases not ascribed to compounds of each of them with some other, in place of being confined to the one gas alone?

Partly, I imagine, because no one knows at present what the other component may be. And partly because there is a very conveniently classifying theory for use in the meantime, which sets forth how one, simple, elemental gas may have two or more different spectra under different temperature circumstances; granting always that it exists as a gas at those temperatures, and is not, like Carbon, inert and solid at all but one of them.

M. Thalen has controverted the multiple view for gases in general, not only on the grounds that his deceased, revered, and loved friend M. Angstrom held that each chemical element *could* have only one spectrum under any, or all, circumstances (though how proved is not stated)—but considers he has demonstrated that the low temperature or "Band-spectrum" of Nitrogen, is the spectrum of the bi-oxide of that gas, and not of that gas by itself.

In 1872 (*Proc. R. Soc.*, xx. p. 482) Dr Schuster, the able writer of the Report for the British Association Committee in 1880, held a similar view. But in 1880 he repudiates the idea, and states that no *emission*, or bright, spectrum has yet been found that can with certainty be referred to a compound of Nitrogen and Oxygen; so that he restores the "gorgeous Band-spectrum" to Nitrogen alone; its *line* spectrum at higher temperature notwithstanding.

Dr Schuster is also the hero for claiming the particular Oxygen spectrum we have been describing, viz., the spectrum of minute triplets and a few thin lines, for Oxygen alone; calling it the compound-line, or low-temperature, or simple-spark, spectrum of that gas; but without invalidating in any degree its claim to the strong Line-spectrum which it shows at high electric temperature.

And Dr Hasselberg seems to perform a somewhat similar part for Hydrogen, excepting that there, the high-temperature lines are seen simultaneously, or together, with those of the low-temperature spectrum.

Of these three elemental gases, all of them equally and similarly disputed upon, the case of Oxygen is perhaps the most advanced and instructive.

With simple, direct, uncondensed induction sparks, passing through an Oxygen vacuum tube, every one allows, or will allow I hope after reading this paper, and severely experimenting, that he does, as he should, get that spectrum of minute triplets which I have been describing here at length. And every one also allows, and has allowed it for many years past, that if you send a sufficiently condensed, intensified, jar discharge of induction electricity through the same tube, the spectrum immediately changes to something perfectly different, viz., the high-temperature, or line-spectrum of Oxygen, as set forth on strips Nos. 7 and 8 of our Index Map, Plate LXXVII.

The facts therefore are allowed, and it is only the interpretation of them which is different with different parties. One side insisting on a different vibration of the same particles of Oxygen, under the two kinds of electric sparks, being the only reason of the two totally different spectra; and the other declaring that with the milder spark, the Oxygen *must* have entered into momentary chemical combination with something else that was already in the tube, but unperceived by, and totally unknown to, its owner.

There is little doubt too that there may be many more infinitesimally small things in a tube, or extractible out of its sides by electric discharge, than chemical philosophy is at present aware of. While even with so gross a matter, as CH in sufficient quantity to give strong spectral bands,—we have seen London scientists going on for years preparing CO, and quite unconscious that they were at the same time manufacturing CH with it, even *pari passu.* Some particular kinds of gaseous impurity that may be in a tube, adhering to its sides or otherwise,—I have shown in this paper may be easily submerged by greater density of another gas thrown into it. But if that gas be contaminated at its birth with some other, either not yet recognised by Chemistry, or in too small proportions to be detected by any existing chemical method,—who shall help! There may have to be a new chemistry elaborated, dealing with infinitesimally small combining quantities. But that is something so hazardous to count upon, that we may well in the meantime accept the varying temperature vibration theory, as a mere method of classification; and then we shall find that there is an immense deal yet to be done, in order to collect even the plain and practical facts of the spectra of the best known gases, in such degree of purity as they can be prepared in, at present. For with every *elemental* and *permanent* gas, *i.e.*, gaseous at all known temperatures and moderate pressures,—there seem to be three different temperatures under which its spectrum in some

shape may appear, viz., the temperature of the condensed spark, the simple spark and the atmospheric or auroral.

With *compound* gases, there are only the two latter temperature stages, viz., the simple spark and the cold auroral; for the high-temperature condensed spark resolves them instantly into their known chemical components, which then give out their own elemental spectra. While with *Carbon*, and every other similar solid, there is only one temperature stage; viz., that highest one at which alone it can be volatilized.

To return then to the *elemental* and *permanent* gases, as the completer system, how little do we know yet of all three varieties of spectra belonging to any one of them;—not to say anything of each variety, in order to be fully understood, requiring to be made to appear *first* as an emission spectrum with bright lines in a dark field, and *second*, as an absorption spectrum, with the same set of lines but dark in a bright field.

Suppose we take Oxygen again as an example.

1. Its emission spectrum of bright lines in the condensed spark, or jar discharge has been grandly studied by KIRCHOFF, THALEN, PLUCKER, and HUGGINS in long past years, with a most satisfactory cataloguing of Wave-length places again and again,—and yet it was left for me to discover the earliest of its ultra red lines last summer. But no one has yet seen either that line, or I suppose most of the others, as dark, or absorption, lines; though Professors LIVEING and DEWAR are now working at that subject, and towards that end very magnificently in the Cavendish Laboratory at Cambridge.

2. Oxygen's emission spectrum in the simple spark, viz., the spectrum of minute triplets and a few thin lines, has been set forth in this paper at some length, though elsewhere, and particularly in London, only 4 lines of it have been recognised; but none of them have yet been seen by any one as a dark absorption spectrum, so far as I am aware.*

3. At the atmospheric, the cold, or auroral, temperature no one has ever yet seen any bright, or emission, spectrum of Oxygen. But two persons are said to have recently seen its dark, or absorption lines connected with that very low, or non-fiery, temperature; and it came about in this manner.

After I had for years and years besought, but in vain, the rich London Societies, or the Government to make the enormous experiments which are necessary for the purpose,—these have recently been made in St Petersburg! There, in connection with the University of that city, M. EGOROFF, with his friend M. KHAMANTOFF,—so far as we can trust the rather too scanty information yet given out,—established a horizontal tube 66 feet long with glazed

* I thought, on the first discovery of 3 of these triplets, that they could be recognised in ANGSTROM'S Normal Solar Map as dark Fraunhofer lines, but I delay now either affirming or refuting that idea, until I have made more satisfactory and exact observations on the Solar Spectrum itself.

ends; filled the tube with pure Oxygen gas at several atmospheres pressure, looked into it at the near end with a powerful spectroscope, while an incandescent lime-light was placed outside the other end;—and then, pictured on the bright continuous spectrum of that light,—they inform us they saw and measured certain most distinctive bands and groups of dark absorption lines. These were totally different in both arrangement and spectrum place from any of the bright lines of either the high-temperature, or low-temperature, sparkings already described for Oxygen,—but they were held, nevertheless, to be Oxygen lines, because they were only seen when that one particular gas, in immense excess, was introduced into the tube; while there was quite lowering enough of temperature between the simple induction-spark and atmospheric temperatures, to permit of another kind of gaseous vibration being set up, if that was already allowed to be possible, between the simple, and the compound, spark, by reason of the latter's superiority therein.

The special interest, however, of the St Petersburg experiment, if confirmed, depends still further, and more pointedly, on this other observational fact; viz., that the dark absorption groups which MM. Egoroff and Khamantoff saw in their Oxygen tube they declare to be identical in build, and spectrum place, with the powerful groups of similar dark absorption lines, telluric chiefly, but perhaps partly Solar, or extra-Solar,—seen by all the world constantly in the spectrum of the Sun's light, and so well known there as Fraunhofer's great A and great B. While still more recently M. Cornu in Paris, by an exceedingly elegant method of his own, having lately succeeded in eliminating from the $\alpha$ (Alpha) band of the same Solar spectrum, both the Solar metallic and the terrestrial water-vapour lines, found the residual markings so exactly the counterparts of the now thoroughly understood geometrical construction of the preliminary bands of great A and great B,—that he can pronounce with the utmost certainty for their being all three born of one and the same kind of gas; though whether, after all, that gas be really Oxygen, the world will be better instructed when other physicists have repeated the bizarre experiments of the Russian capital, and vouched for the purity of the gas introduced there into the long tube.

Even concerning Oxygen then, our knowledge is but rudimentary, and in fragments; while of Hydrogen, and Nitrogen, how very little have we yet seen of one, possibly two, of the three double phases which the temperature theory indicates must belong to every one of such permanent gases; and all of whose phases too, our observations in this paper promise will be found replete with the most exact Natural writing, whenever they be efficiently and sufficiently interrogated by man.

# APPENDIX I.

## PROF. ALEX. S. HERSCHEL'S LETTER ON THE GREEN BAND OF CO, AND ITS EXPLICATIONS (EVENTUALLY CONDENSED INTO PLATE LXXVIII.).

*Dated November 20th, 1883; College of Science, Newcastle-on-Tyne.*

The chart of the green band's lines* is beautiful; it is quite a page of the spectrum itself much more clearly laid down, I am sure, than I have ever seen the tribe of linelets, and I'm astonished how you can have both discovered and plotted so many perfectly!

You have far surpassed the sight you gave me last, I find, of the CO band, by dividing "broad" and plenty of the fine lines too, into pairs and triplets. This is a real triumph, that I couldn't well believe possible, when I discovered it by trying to recognise your new map in the drawing and measures that I took of SALLERON'S CO tube's *green band* (with five Sulphide of Carbon prisms) in December *last;* and couldn't make them fit immediately, until I found that you had duplicated and triplicated numbers of the lines that I recorded "broad," "winged," "united pair," &c., only, so that there is a profusion of new dissections of the band that you have managed now to supply for its anatomy! And then IO TRIUMPHE! in searching over the spaces of my "readings" to identify your lines with, I lighted luckily *on the key* of the construction, which is simplicity itself, and couldn't well be exceeded in the exactness with which your new map reveals it! *Lux in tenebris,* what a happy and glorious release you have disclosed to all our uncertainties!

I grounded first on this palpable feature of the measures ,

that while the "leaders," and twin-cub followers open out regularly all down the range, it is not so between the twin-cubs and *the leader next following them,* so that the distances $a$ remain constant, varying from 0·159 revns. to 0·172 revns. in my readings without any symptoms *of expanding,* as far as my list went; so that these "leaders" are simply accompanied *on the preceding side* by a companion pair that is at an invariable distance from them! In other words, the "leaders" form *a scale-in-chief* by *themselves,* and a little distance *preceding it* is just such another scale of fainter twins, overlying the former scale.

How will this relationship, I asked myself, be borne out *in the thronged part* of the band between its front edge and the "crossing" point, *beyond which* point as far as the "green giant," it is as plain as the alphabet?—The answer was to take up the constant distance $a$ between any

* This was merely the raw record-slip taken at the Instrument, in the manner which I specially arranged for all the Spectra described in this paper.—C. P. S.

leader-line and its precursor shadow-pair from any good specimen conjunction of them on your map, and to apply it successively to all the leader lines from near the "green giant" backwards across the crossing-point and on into the thick of the mélée that precedes it, right up to the first edge of the band. The result was, to my joyful surprise that it *accounts instantly, and in toto for every* single line of the band laid down on your map! The band is *simply two exactly similar* single-rank line progressions laid over each other displacing one of them slightly on the other; and while one consists of single strong lines, the other is formed of fainter, closely double ones. You will see this by the enclosed card strips* along the top edge of one of which your map of the band *is exactly* copied, while under it the members that compose the close double, or fainter series are prolonged so as to produce a linelet progression by themselves. On another card the rest of the band's linelets are figured, also in a single-ray progression of (in red ink) strong single lines; by applying this card with its left hand leader *at No. 5 line* of the *natural* delineation, you will see that it includes all the lines *not* prolonged downwards or abstracted from that stripe to form the partial stripe of duplex lines; and by then shifting it leftwards till its beginning coincides with No. 1 line of the natural band, you will see too that it then exactly covers all the duplex line series of the natural band.

Besides the two constituent bands' precise resemblance to each other, there is also this link of connection between them, that the ruler of the following band is not placed *anywhere*, but ON *No. 5 line* of the foremost one. And again there is this simplicity about the single-rank or partial bands themselves, that their intervals are quite distinctly an arithmetical progression of spaces denoted by the series of natural numbers 1, 2, 3, 4, &c. I have plotted in, under each (singular and duplex) portion of the band *a true* simple progression of this kind, so that the eye can judge how nearly each of the two tributary bands satisfies it, and there is no question, I think that it is, with *some very slight* disturbances here and there, the simple rule of formation of them both? Instead of being, therefore, a linelet band of the most curiously involved *complexity*, as it at first sight looks by its "crossing" lines and close pack of crowded lines near the front edge, the ruled CO green band is really *the very simplest* in its mode of construction that I *think* has yet been met with in Spectroscopy! The way in which your sharp resolution of the two "crossings" lines themselves into a minute triplet and a minute doublet respectively agrees with the conjunction is by itself a wonderful corroboration of the structure. But without the clear and *precise* resolution *of all its lines throughout* with the most accurate autographic measurement that you have effected, it would evidently have been quite impossible to recognise and establish it in its microscopic mixture! A good example of the powerful discrimination that you have used upon the band occurs in its very first line, which I had noted "BROAD," only, in my little sketch of measurement, but which you have mapped as a pair Nos. 1 and 2 of the band, just as accurately placed as the other equivocal looking linelets of the band are all clearly and exactly broken up and divided into their proper places in the dual band.

The displacement between the band's two parts is 10 $(1+2+3+4)$, unit spaces of the structure, which is neither an indifferent interval nor an indifferent number of unit-intervals of its structure; so that the two parts can't be described as two independent overlying bands belonging possibly to two different gases. But yet the *duality is* singular, as if either sever-

* These very ingenious card strips of Prof. HERSCHEL'S, being unsuited to book-illustration,—it occurred to me, to prepare Plate LXXVIII., including them both and the manner of working them, but in one statical view. This Plate afterwards had his approval, though with a *proviso* touching ideal accuracy, which he has touched on in Appendix II. page 43.—C. P. S.

ance into constituents physical, or constituents chemical, of the CO, was accomplished by the spark; and the tetravalence of Carbon *unsatiated by the* bivalence of Oxygen, or in other words the propriety that chemists admit (our chemical Professor, Dr BEDSON, just now suggests to me) of regarding Carbon as sometimes divalent like Oxygen in forming neutral combinations such as CO, may be the origin of (  Tetravalent Carbon. Divalent Carbon. ) the double structure of this CO linelet band. At any rate it will interest me very much to see if I can make better sense now, and trace some similar evidence, of duality perhaps in other "Carbon" records of the CO citron, and Blow-pipe-green Band-lines that I have, distinctly enough measured I daresay to tell the same tale if they are carefully interrogated.

A. S. H.

# APPENDIX II.

## PROF. ALEX. S. HERSCHEL'S LATER REMARKS ON PLATE LXXVIII., AND AN IMPROVABLE POINT IN ITS SCALE OF REPRESENTATION.—May, 1884.

Two distinct spectra closely resembling each other, together form the Green band of Carbonic oxide figured in the Plate LXXVIII.; one of which consists of single linelets, and the other of slowly opening double ones, or of linelets coupled together in close pairs. If the whole unilinear spectrum is shifted together to the left until its first line coincides with the leading one at the band's least refrangible edge, all its lines fall nearly into coincidence either with the middle place, or else with one or other side-line of the several linelet pairs of which the remaining bilinear portion of the spectrum is composed.

An ideal spectrum is placed for comparison above and below the two component spectra of the band, forming an arithmetical series of micrometer-revolution, or of sensible dispersion intervals, representing with a suitable scale-unit of measurement, the series of natural numbers 1, 2, 3, 4, &c. The necessary data for replacing this array of gradually increasing micrometrical intervals by a similar, more scientific arithmetrical progression having a wave-number unit instead of a micrometrical dispersion one for prime measure of its successive terms or intervals, was not exactly procurable in the state of the instrument's adjustment; but the small regular differences which are noticeable in the Plate between the two observed spectra and the arithmetical comparison series of micrometrical line intervals, are, it may be remarked, of exactly the description in direction and in varying magnitude which the provisional substitution in the Plate of a micrometrical for a wave-number series of successive intervals would correspond to, and serves sufficiently to account for. Were such a replacement of the provisional array by a corresponding wave-number one made with perfect certainty and correctness, it would seem to be a safely legitimate assumption to conclude, that the small visible departures of the ideal from the observed spectra which their comparison together exhibits on the Plate, would all, then, be quite satisfactorily obliterated and removed.

A. S. H.

To which I, as the Observer, may probably be allowed to add,—*not* "*quite removed.*" For wherever there is numerical observation aiming at exactness, there will always be errors of the observer to some extent. But I must confess I have been well pleased to see the *smaller* amount of the apparent errors of observation, when one Natural System of spectral lines is compared with another, as in the lowest compartment of Plate;—than when either one of them is contrasted with the artificial screw-unit scale, as shown *first* at the top of the plate, and then near the bottom of it; viz., Plate LXXVIII.—C. P. S.

# APPENDIX III.

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## MR CHARLES F. CASELLA'S LETTERS ON THE PREPARATION AND PURIFICATION OF SOME OF HIS LATER VACUUM TUBES.

147 Holborn, London, E.C.,
31*st August* 1883.

To Professor C. Piazzi Smyth, F.R.S.E,
15 Royal Terrace, Edinburgh.

Dear Sir,—I am in due receipt of your favour of the 30th inst., and I must thank you for the kind expressions that you make use of with regard to my Father, as well as for your kindness in communicating with me on the subject of the Tubes.

By train to-day I have great pleasure in sending you three tubes, viz., the 4th $CO+CO^2$ Tube at 0·2″ pressure, and the $CO+CO^2$ Tube at 0·3″ pressure, also the N tube at 12·5″ pressure—all of which I trust will be entirely to your satisfaction.

This now completes all the Tubes I have had to do for you, and I now beg to give you a formal note of how the gases in the above tubes have been made, the various processes being as follows.

Hydrogen, by electrolysis of water. Oxygen I tried as above, but the manufacture of the gas was so dreadfully slow, that I had to resort to a chemical process, viz., by heating chlorate of Potass, which I think is the most satisfactory way of obtaining Oxygen.

Nitrogen, by boiling Ammonium Nitrate; of course the preliminary bubblings yielding impure Nitrogen, were allowed to escape, and only the subsequent bubbles of gas collected. Carbonic Acid, by heating ferro-cyanide of Potassium with eight times its weight of sulphuric acid.

Coal-gas simply by connecting the gas jet with the gas receiver connected to the Pump.

$CO+CO^2$ prepared by heating crystallised oxalic acid with concentrated sulphuric acid.

All the above gases were prepared in glass retorts, then passed through water into glass receiver, which latter was connected with the Pump by glass tubes, and a very delicate small steel tap; the various drying tubes used were—next to the end-on tube a Caustic Potass tube; immediately next to which was an Anhydrous Phosphoric acid tube: then came a four-foot pummice-stone tube saturated with concentrated sulphuric acid; next to which was a small chloride of Calcium tube, and then came the small steel tap separating the Pump from the gas receiver. Before making each gas the trough, receiver, and everything were thoroughly cleaned, and fresh water and new drying tubes used each time; a new Phosphoric Acid tube being used for each tube.

I trust I have made myself clear in all the above details, but if I have not, pray do not hesitate to ask me for further particulars.

Assuring you of best attention at all times, and hoping that at some time I may have the honour of being specially mentioned in connection with the preparation of these tubes, which

I confess require the greatest personal thought and attention.—I am, dear Sir, yours very truly,

CHARLES F. CASELLA.

*P.S.*—Your note of the 31st just to hand. I will carry out your suggestion by using naked copper wires instead of gutta-percha covered ones, which already are suspended across my laboratory with a pair of leads coming down to each Pump.

Before doing so, however, may I have your opinion on the following suggestion in opposition to yours, namely, the various strong and damp fumes the naked wires would be subjected to, would create a strong oxidation on them, and would not therefore the current, instead of conveying one gas into the tubes, which gas we already are acquainted with, carry a variety of "gaseous" all sorts into our tubes.

This is a mere hypothesis of mine, and therefore please take it for what it is worth.

C. F. C.

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LONDON, E.C., 13*th Nov.* 1883.

DEAR SIR,—Your favour of the 9th inst. has duly reached me, and I have now much pleasure in telling you that I am back again in office, having returned last week.

Before being able to say that I am ready to commence vacuum tube work again, I must tell you that my pump room or laboratory is without pumps, they having all become spoilt and broken by wear and tear.

To make fresh ones will take about two or three weeks, they being very elaborate but exquisite instruments.

Please state how many olefiant and acetylene tubes and at what pressure you would like.

I will note all my chemical proceedings, and also let you have an account of those last sent, which is as follows, viz.:—Action of Nitric Acid on pure copper filings (turnings), gas collected in a receiver in water, and communication from receiver to pump, the gas first passing through four drying tubes as follows, viz.—(1) Chloride Calcium, (2) Anhydride Phosphoric Acid, (3) Anhydride Phosphoric Acid, (4) Caustic Potash. Minor details, &c., were conducted as before, but with the same care in every respect.—Yours truly,

CHARLES F. CASELLA.

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Previous to these chemical operations of Mr C. F. CASELLA, his father, Mr LOUIS P. CASELLA, had had some curious experiences with the wires forming the electrodes of his vacuum tubes.

Platinum wires usually blacked the inside of the bulbs; wherefore he then tried gold,—the following recommendation of that metal in the *Proceedings* of the Royal Society, London (and subsequently reprinted in the *Philosophical Transactions*, Part I., for 1884, page 51), having been brought to his notice:—

"Of all *metals* affording materials for electrodes, gold appears to be the best; its spectrum is a weak one, containing comparatively few lines; it is an excellent conductor of electricity, and it is not attacked by solutions of metallic chlorides."

No sooner, however, did he try this highly commended material than the insides of his tubes were brilliantly, opakely, and utterly gilt by *it*, combined with the six-inch induction sparks employed. He had, therefore, to fall back on aluminium wire and to use that very thick, or between $\frac{1}{16}$ and $\frac{1}{12}$ inch in diameter.

C. P. S.

# APPENDIX IV.

### SEE THE THIRTY-ONE PLATES, FOLLOWING AFTER THE PRINTED MATTER.

Viz. 29 Plates, each opening to 18 × 11 inches, and showing what they contain on a 40 foot spectrum length from A to H;

1 Plate, folding out to 42 × 11 inches, giving approximate and contracted views only, of whole spectra, 26 inches long from A to H;

And 1 Plate, folding out also to 42 × 11 inches; but showing what it contains on a spectrum length of 220 feet from A to H; a length erroneously printed in earlier pages herein as 120 feet only.

# APPENDIX V.

### ON THE NUMERICAL "WAVE-NUMBER" SPECTRUM SCALE OF ALL THE PLATES.

The regularly altering number of theoretical Waves of Light at each part of the spectrum, contained in a certain constant unit of length, and called for shortness "Wave-number," has been adopted here, rather than the successive lengths of each of such waves, or "Wave-length," as a practical scale for each of our spectrum pictures—because it gives a most desirable mean between the oppositely exaggerated views of Prisms on one side, and Gratings on the other. And the Inch was at the same time employed as the unit of absolute length referred to, because it is not only British, but nearly Earth-commensurable in the best way; viz., as the 500 millionth of the length of the Earth's Axis of Rotation; and it furnishes also a convenient series of numbers for the memory.

The method is, moreover, in the direction of its increase of figures, combined with the universal European mode of writing from left to right,—exactly suitable to Fraunhofer's now nexpugnable order of *lettering* the chief lines of the Solar spectrum from Red A as the beginning, to Violet H as the end; or from lowest to highest, or Earthly ordinary, to Solar transcendental, temperatures. Hence "Wave-number" always goes conformably from Fraunhofer's A to his B, C, &c., and from his so-called $b^1$ to his $b^2$, $b^3$, &c. While the "Wave-length" method, with its reversed numbers, leads the Spectroscopists who adopt it—whether in terms of French or English measures of length—to do despite to the memory of their great predecessor by going backwards with his letters, while forwards with their own numbers; or by beginning the visible spectrum with H and ending it with A, in a manner so confusing to the rest of the world, accustomed long since to invariable procedure from A to H; and also from $b^1$ to $b^4$, in place of the opposite arrangement so recently introduced by the French metricalists.

C. P. S.

### *ERRATA.*

P. 416, line 29; p. 420, line 19; p. 420, line 12 *ab imo*; p. 421, line 20; p. 442, line 19; and back of Plate lxxvi. line 4 *ab imo*, *for* 120, *read* 220, foot spectrum length *passim*.

P. 442, line 12, *for* frebling *read* trebling.

P. 443, line 9, *for* bright-lines pectra, *read* bright-line spectra.

P. 443, line 21, *for* spectrescope *read* spectroscope.

P. 447, footnote, *erase* the latter half.

# Title Page to the Plates of

# Micrometrical Measures of Gaseous Spectra

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## *General Rules for the Method of Representation adopted in these Plates.*

*(1) The Method is Negative, in that Light is represented by Black, and Darkness by White.*

*(2) Every straight Vertical Line, whether thick or thin, and whether close to another or not, within the limits of each horizontal Spectrum Strip, always stands for a veritable and measured Spectroscopic Line, or monochromatic image of the Slit; and nothing else.*

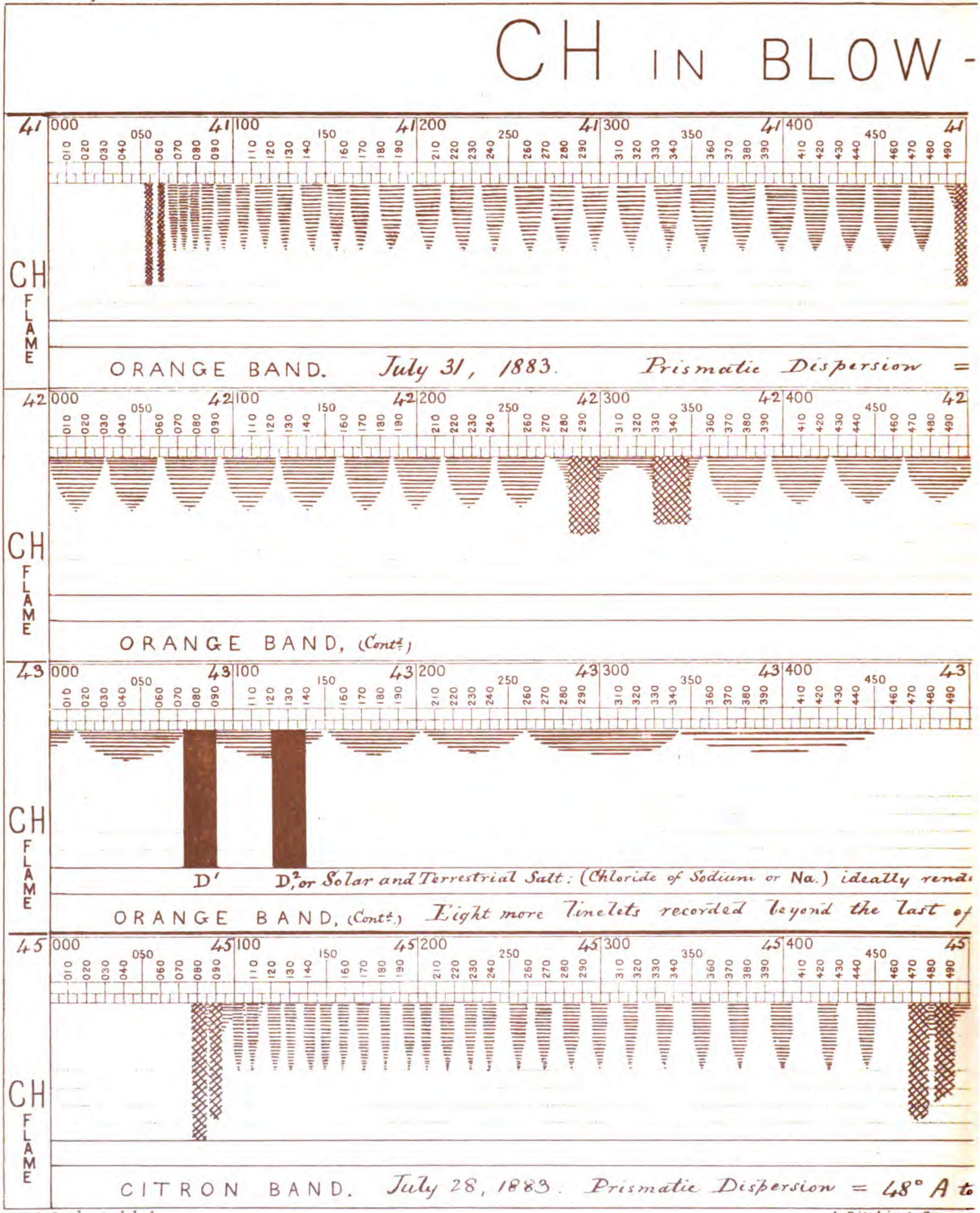
*(3) Lines in any other direction than Vertical,* i.e., *whether horizontal or slanting, and from either side, or both sides at once as in crossed lines, also wavy lines,—are to be interpreted as Nebulous Shade only, in vertical bars or bands of corresponding width at the place.*

*(4) Greater or less Height or Depth, either of Lines or Bands,—is intended, in connection with the amount of ink expended upon them, to typify greater or less intensity and visibility of such Lines or Bands.*

*(5) Cones of shade arranged on a vertical central axis, indicate nebulous bands of pale light, shaded off towards either side very gradually and delicately.*

*C. P. S.*

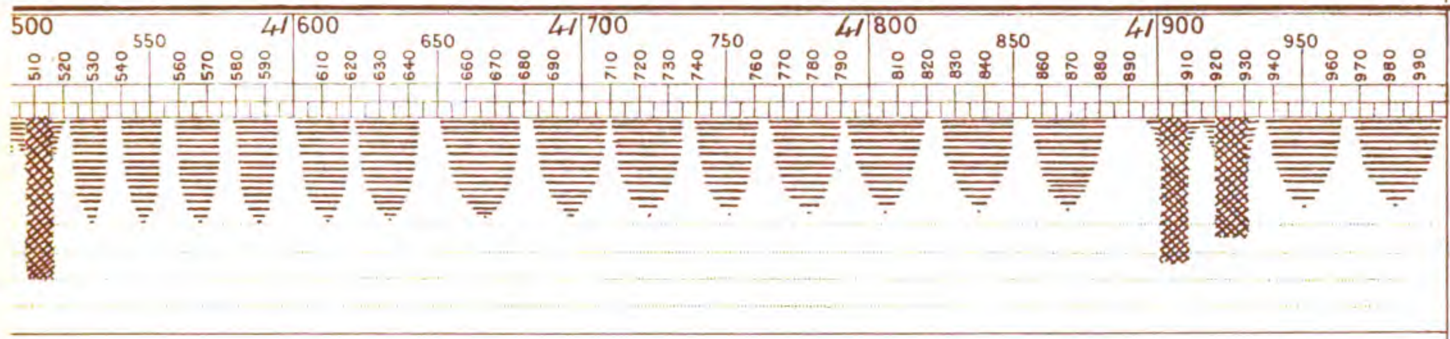
*C. P. S. obs. & del. I.* *A. Ritchie & Son, Photo-lith 1884*



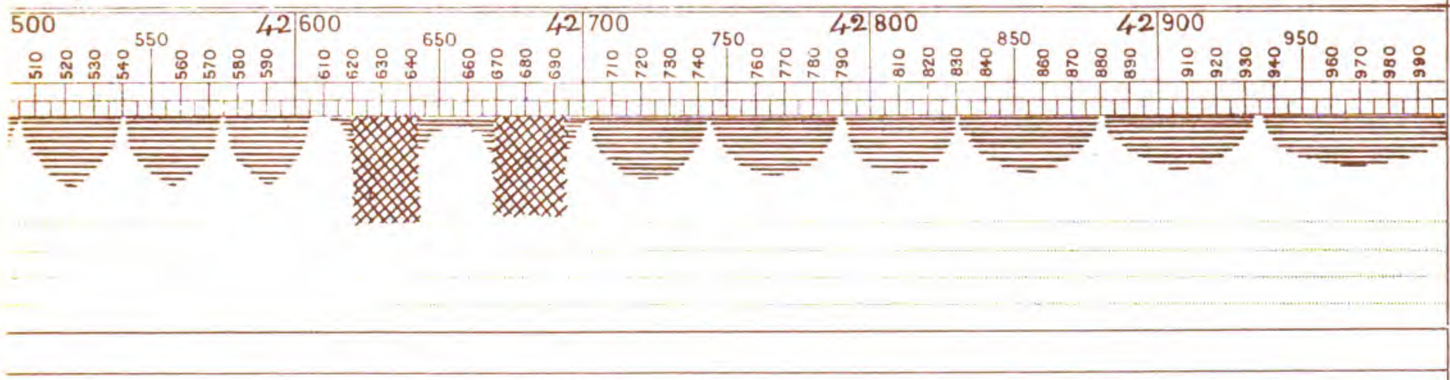

C.P.S. obs. & del. 1.

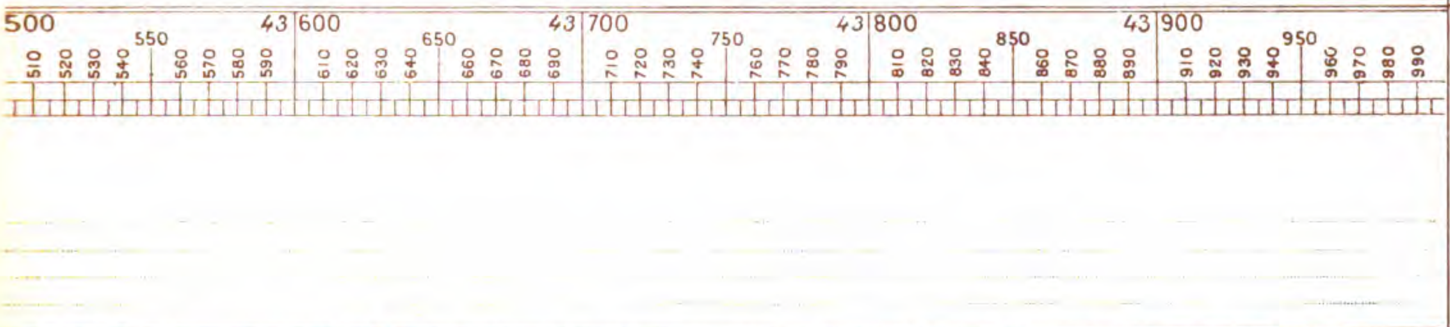
A. Ritchie & Son.

# - PIPE FLAME



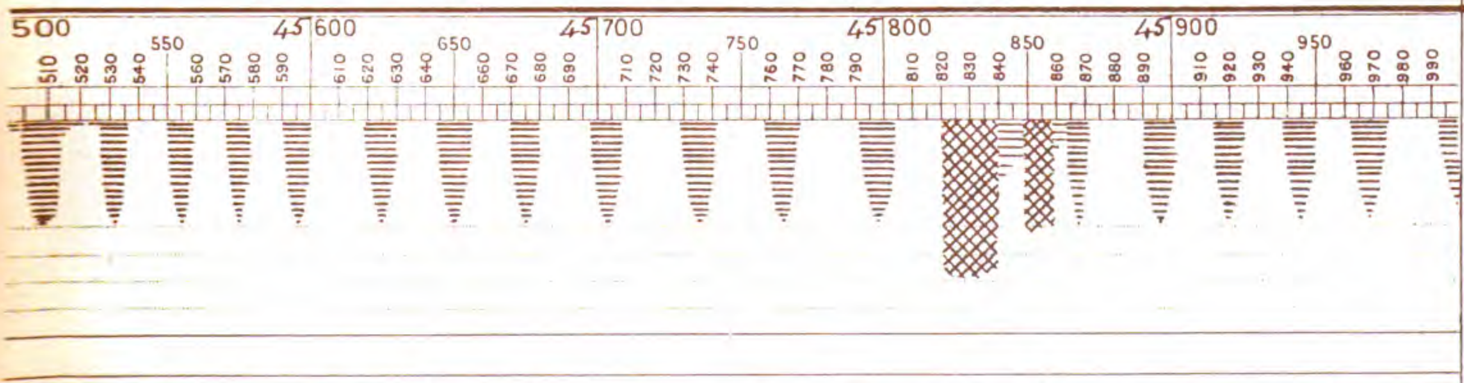

: 37° A to H. The view very faint, diffuse and hazy.




-red to show by contrast the faint, gauzy, airy, open, granular character of the gray Blow-pipe light.

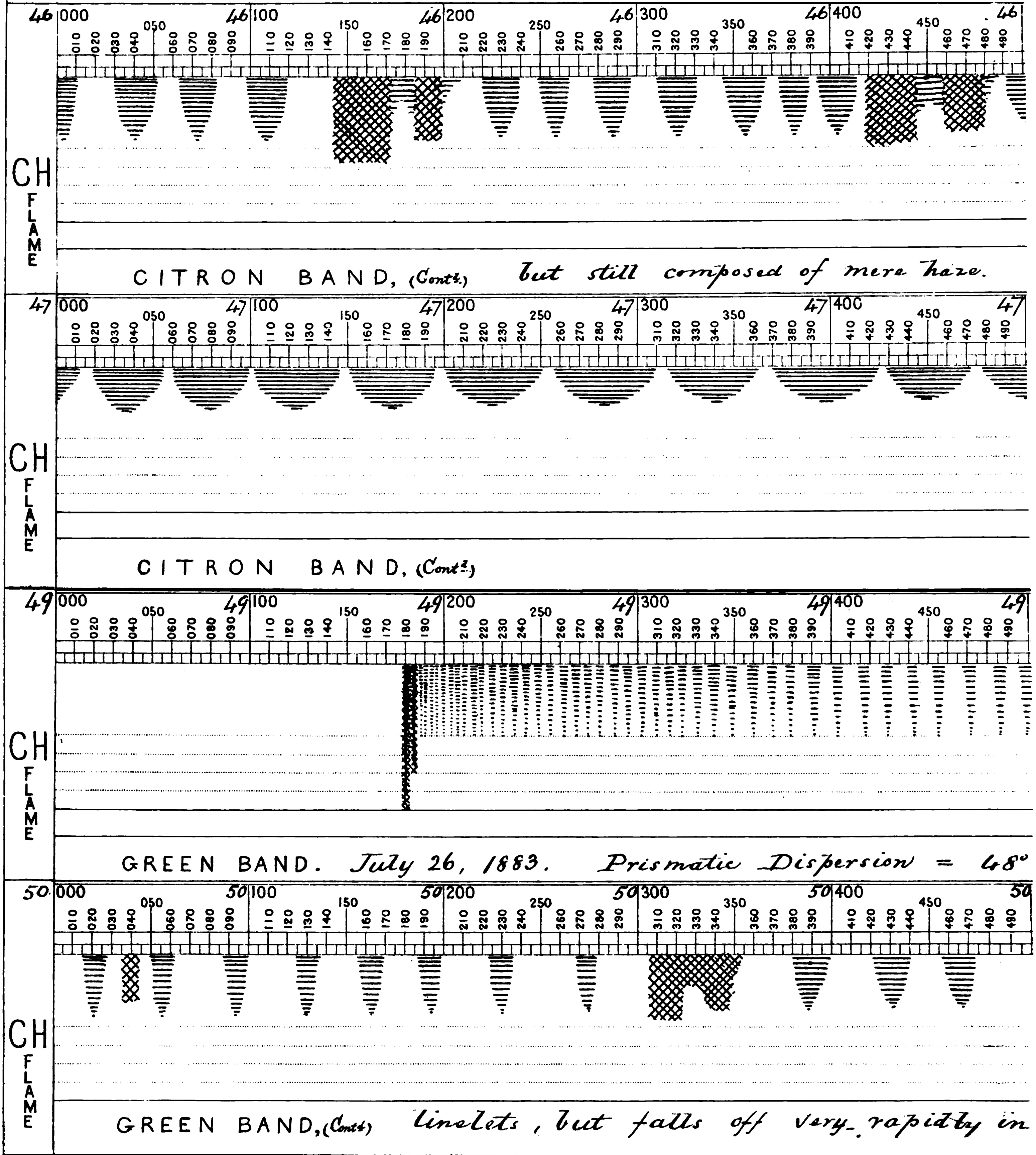
- these, always increasing in breadth and confluent faintness of haze.




H. Lines and linelets far clearer and stronger than in Orange band,

Photo-lith. 1884. T. H. del. 2.

# CH IN BLOW-

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A. Ritchie & Son.

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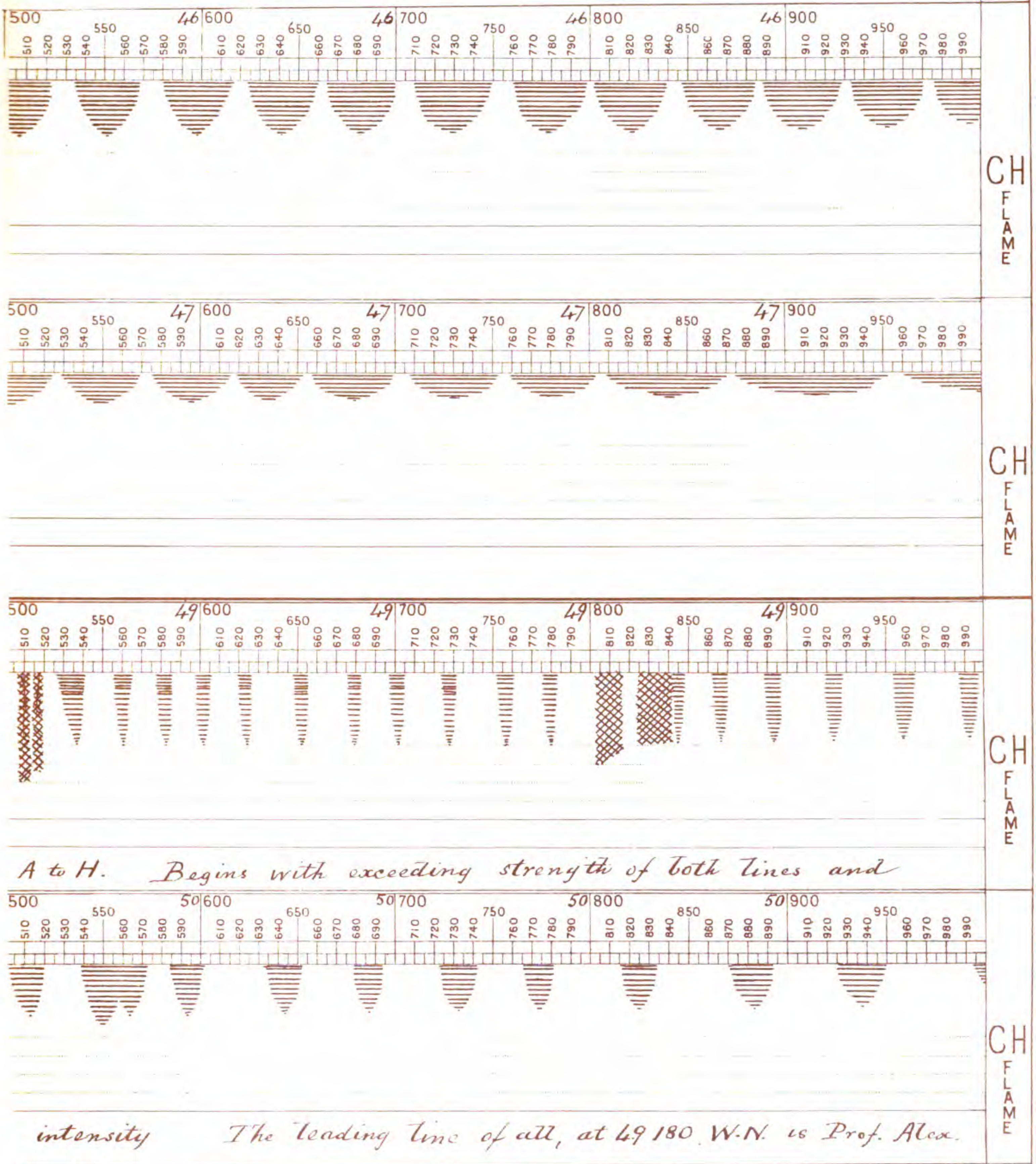
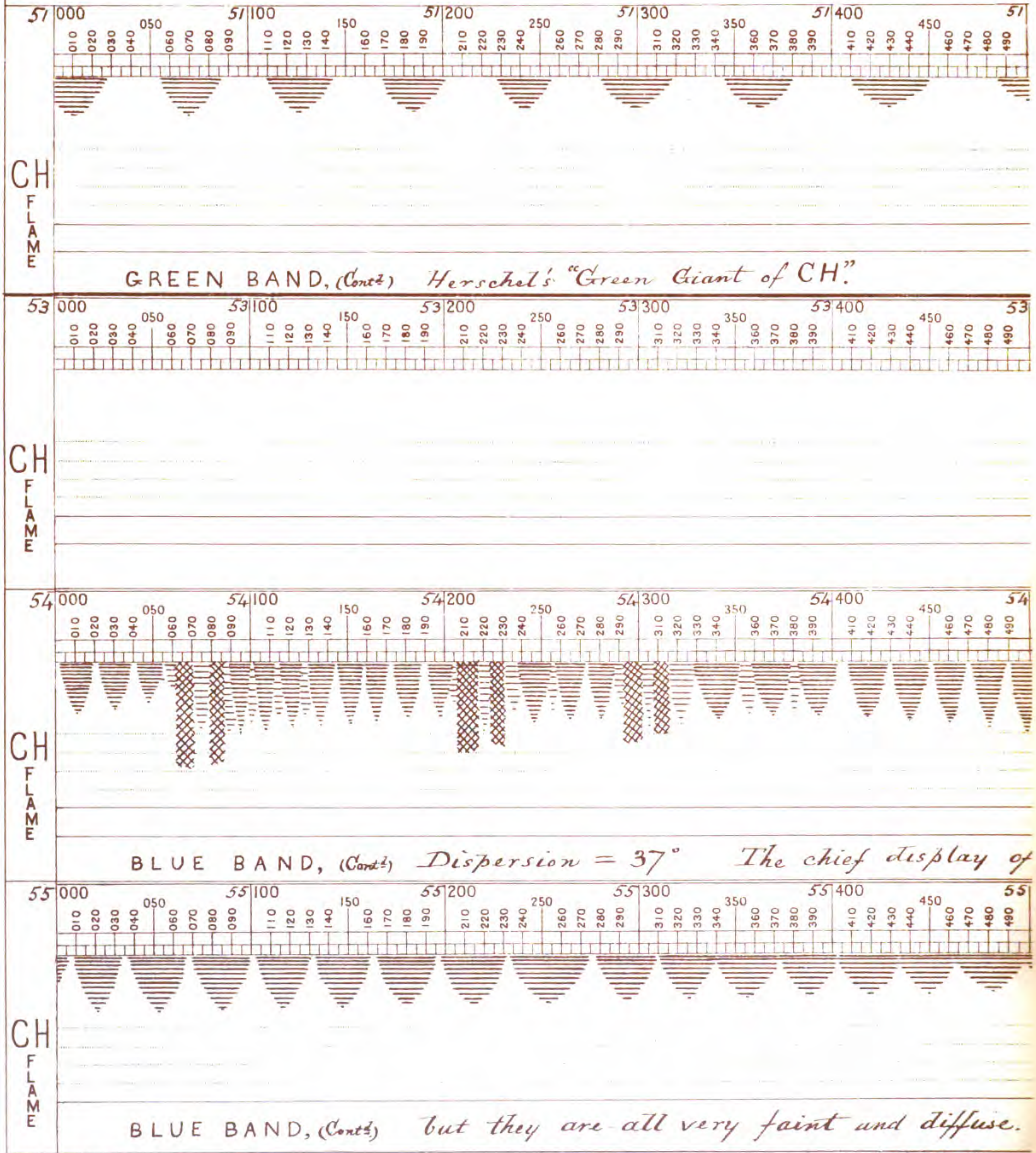



Photo-lith. 1884.

T.H del. 2

# CH IN BLOW-

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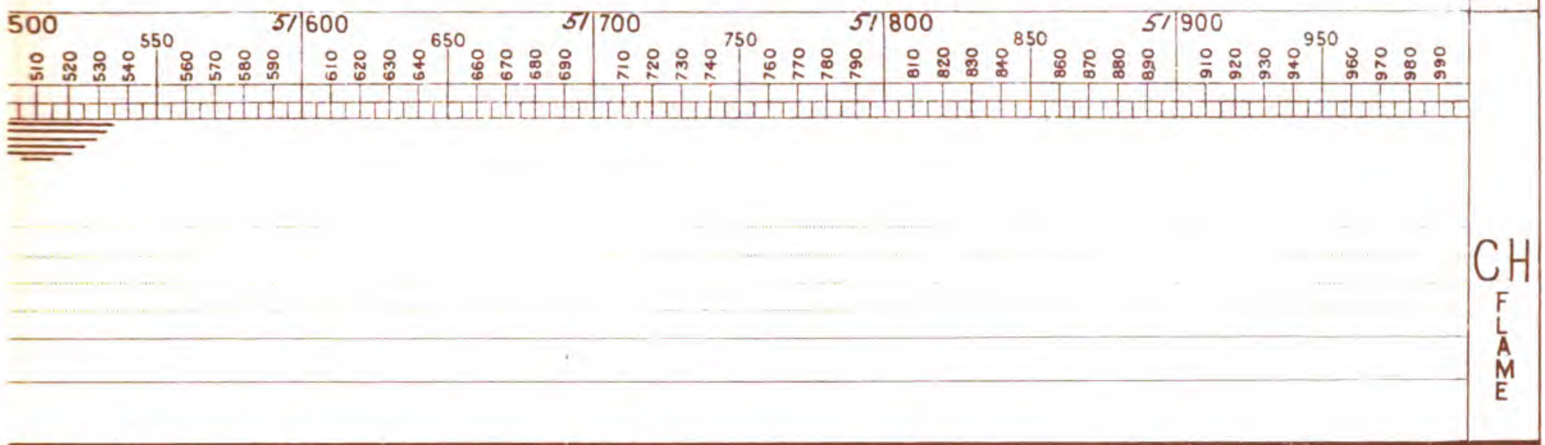
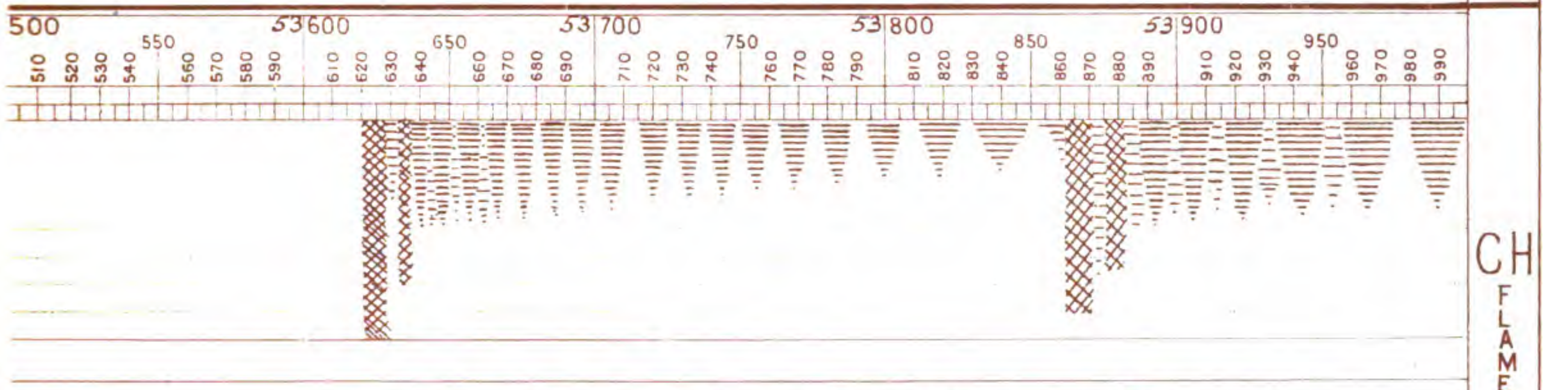
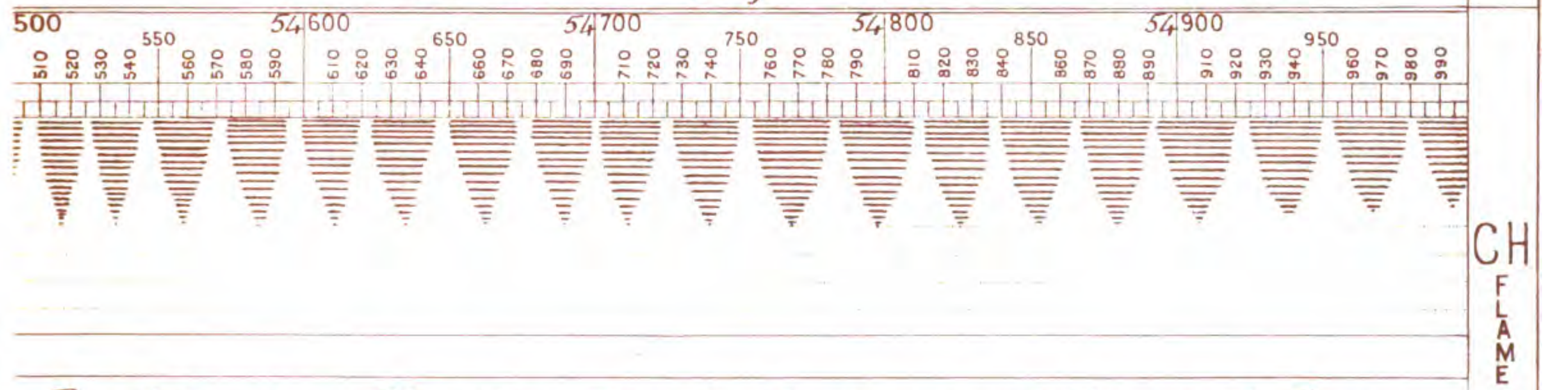
# - PIPE FLAME




BLUE BAND *August 1, 1883. Prismatic*




*unelets is altogether beyond the region of the great lines;*

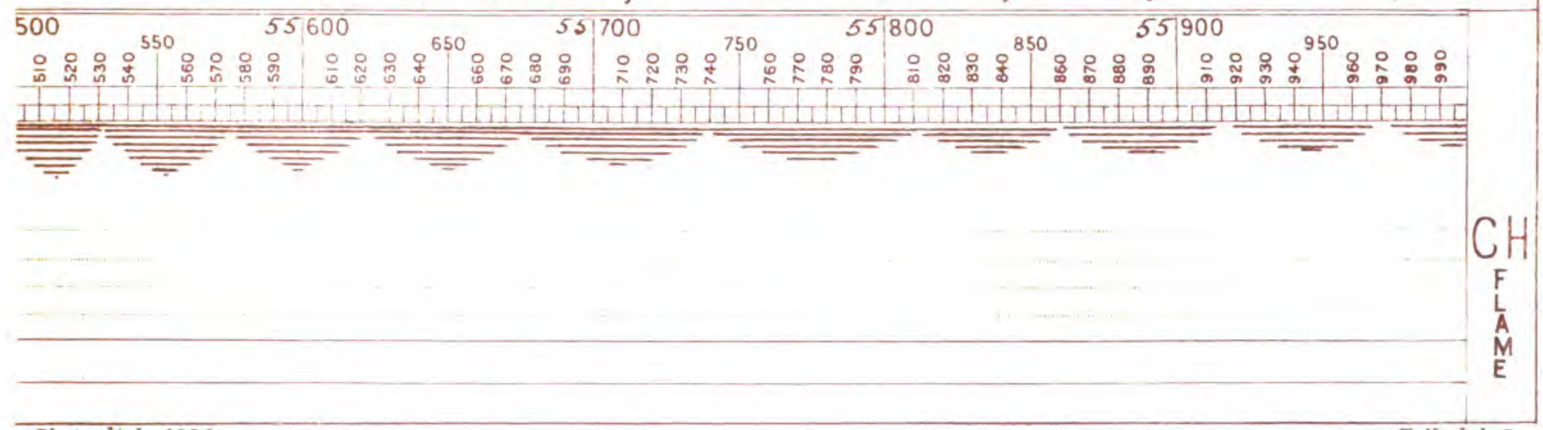
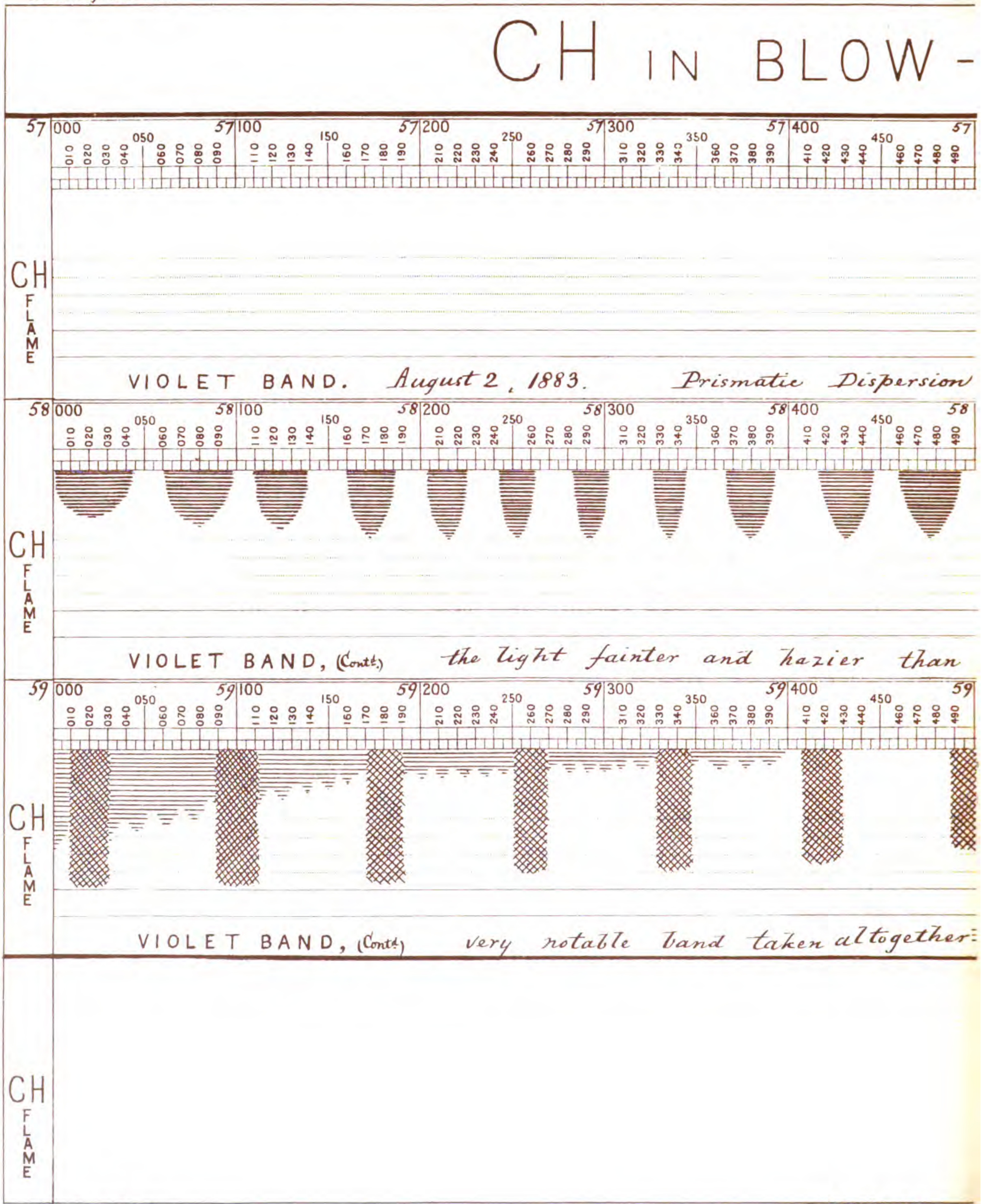



*Photo-lith. 1884.* *T. H. del. 2.*

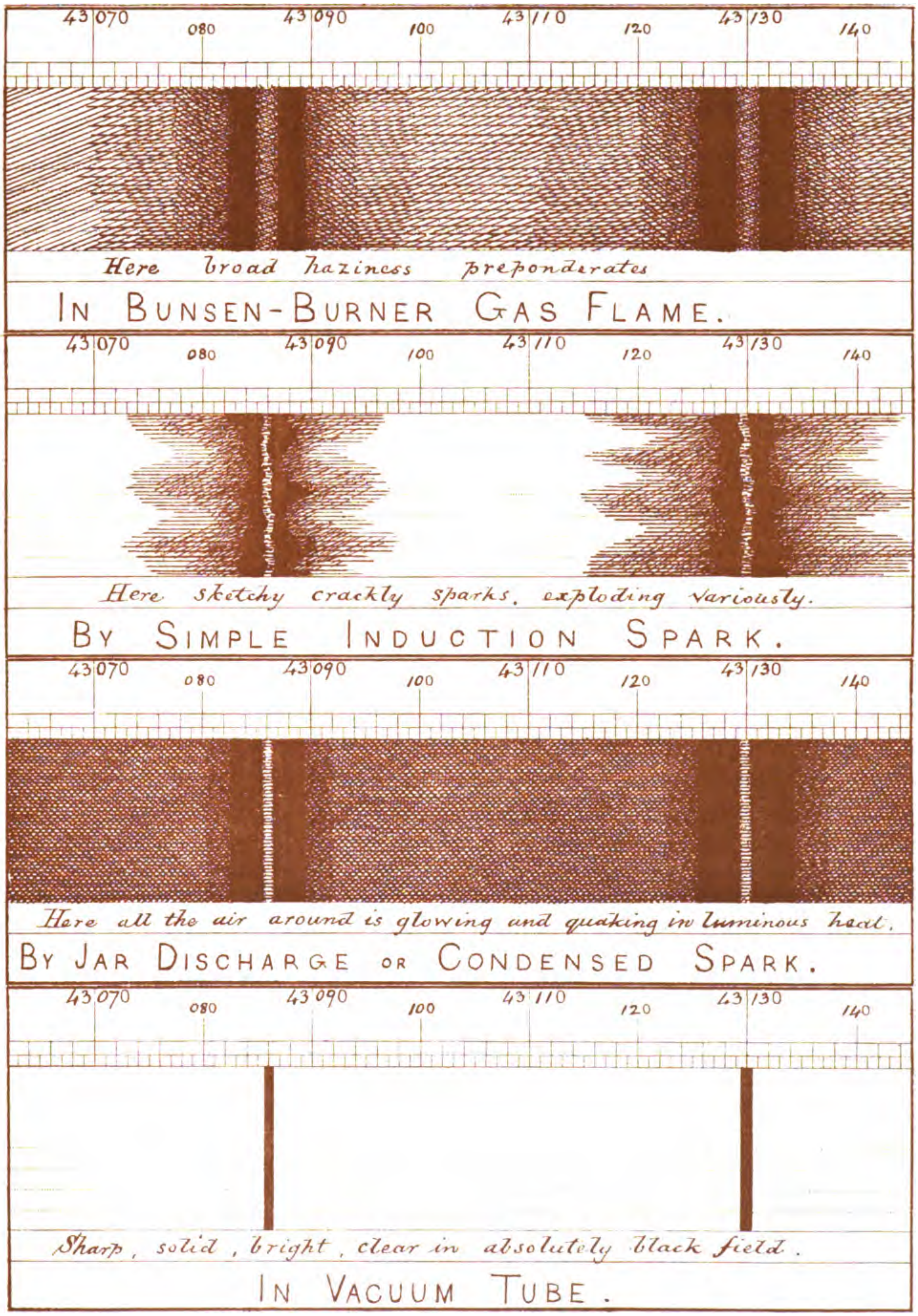



C.P.S. obs. & del. 1.

A. Ritchie & Son.


- PIPE FLAME
= 37° A to H The definition is here more uncertain, and
anywhere else ; but there is so much of it as to form a
CH FLAME
CH FLAME
CH FLAME
CH FLAME

# $D^1$ and $D^2$ of Sodium, or Na., Vapour
## as they appear in different successive methods of incandescense.

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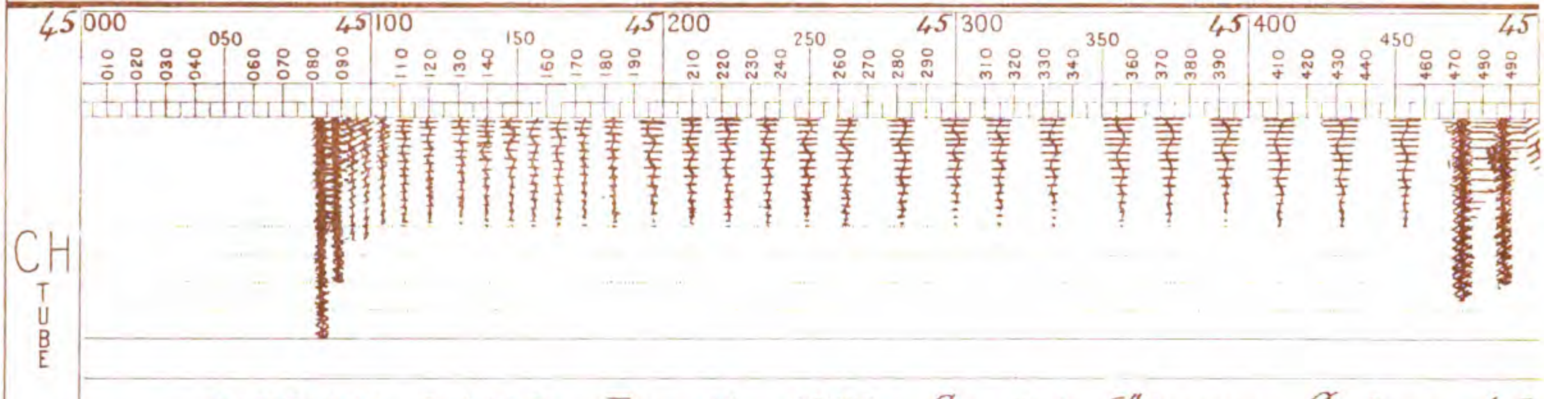
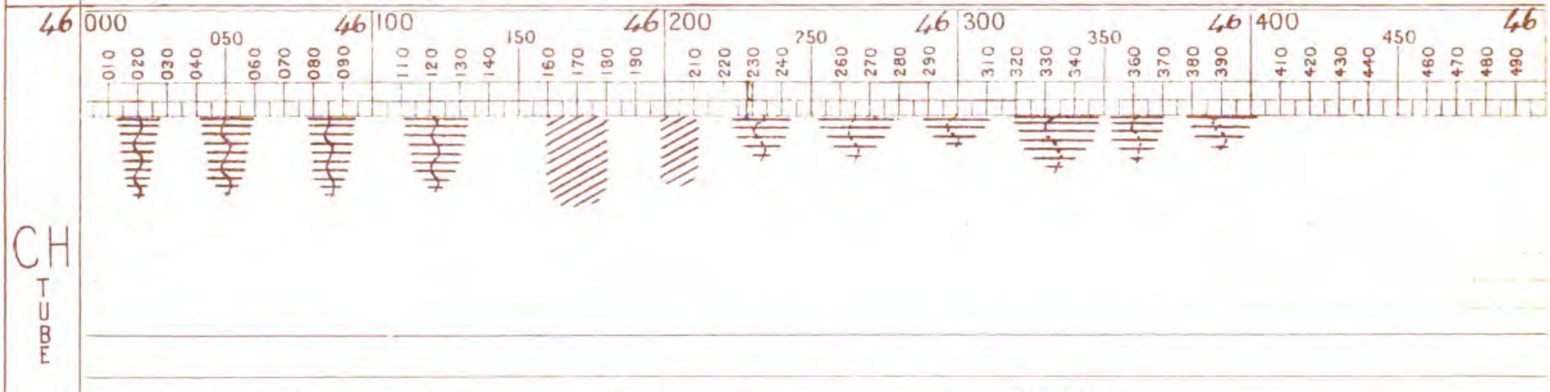
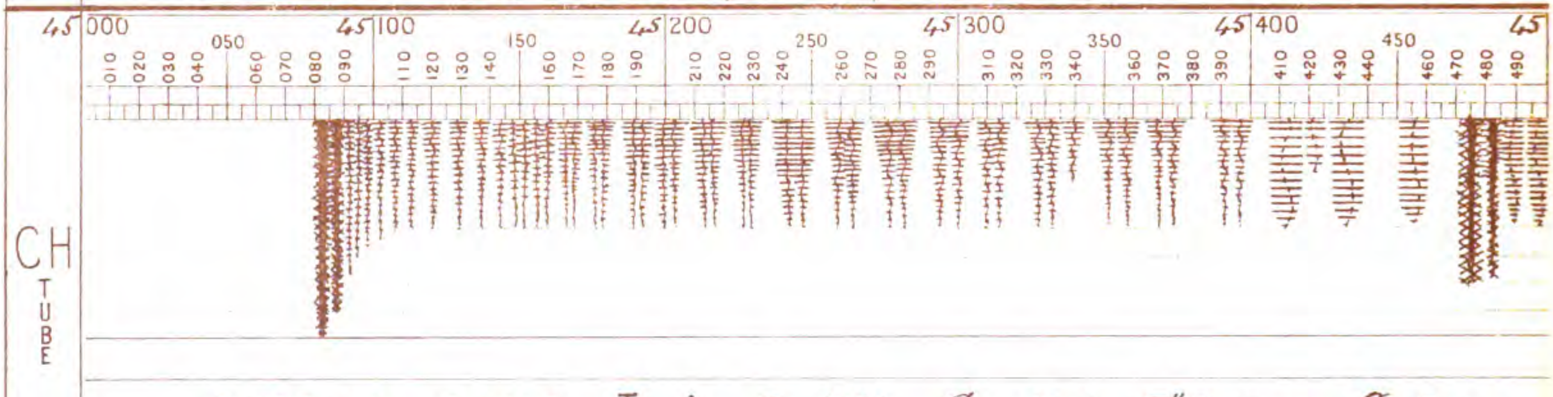
# CH IN VA



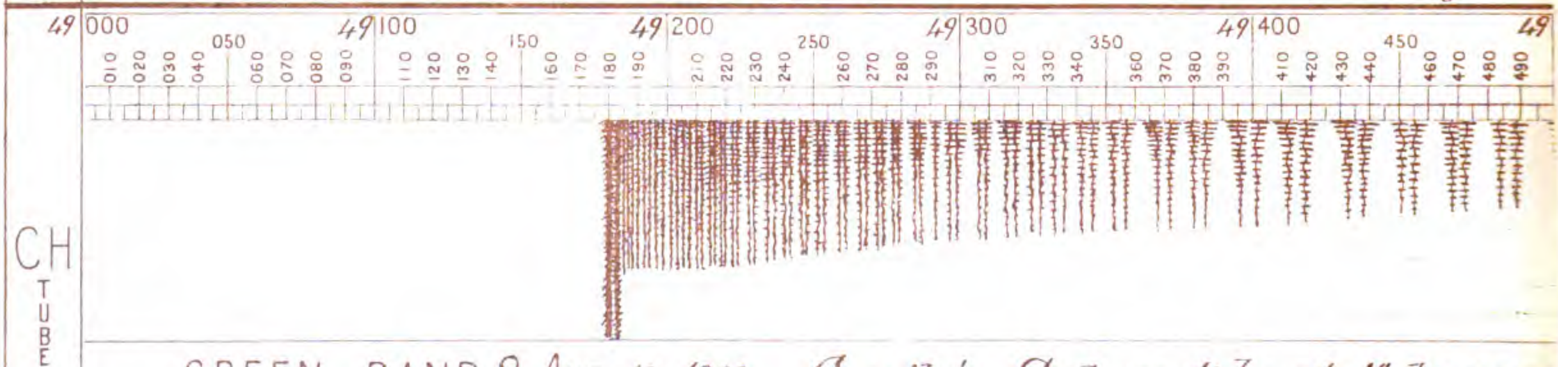

CITRON BAND. *June 18, 1883. Casella's 5" pressure Coal-gas tube*




CITRON BAND. (*Contd.*) *primary in Coil.*




CITRON BAND ♄ *Aug. 18, 1883. Casella's 5" pressure Coal-gas*

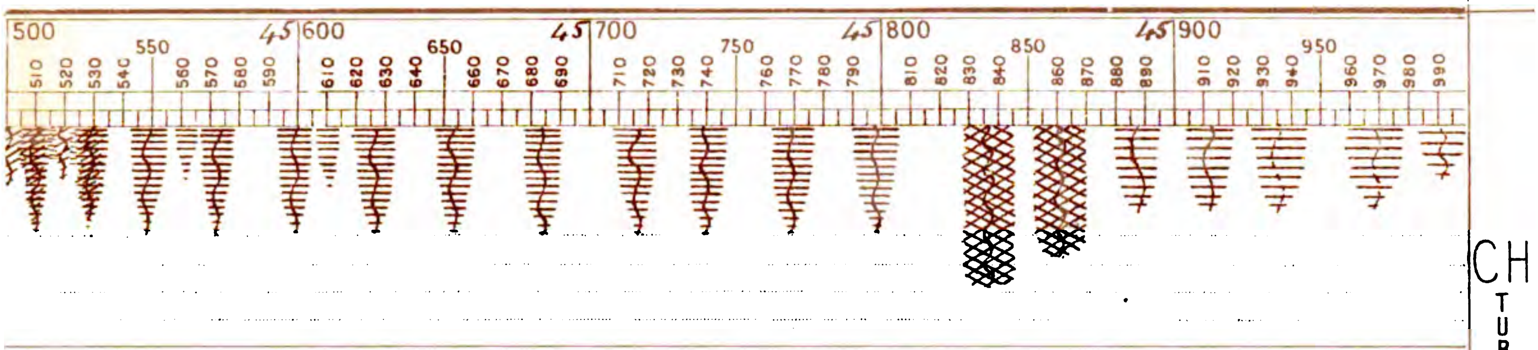



GREEN BAND ♀ *Aug 10, 1883. Casella's Coal-gas tube at 1" pressure*

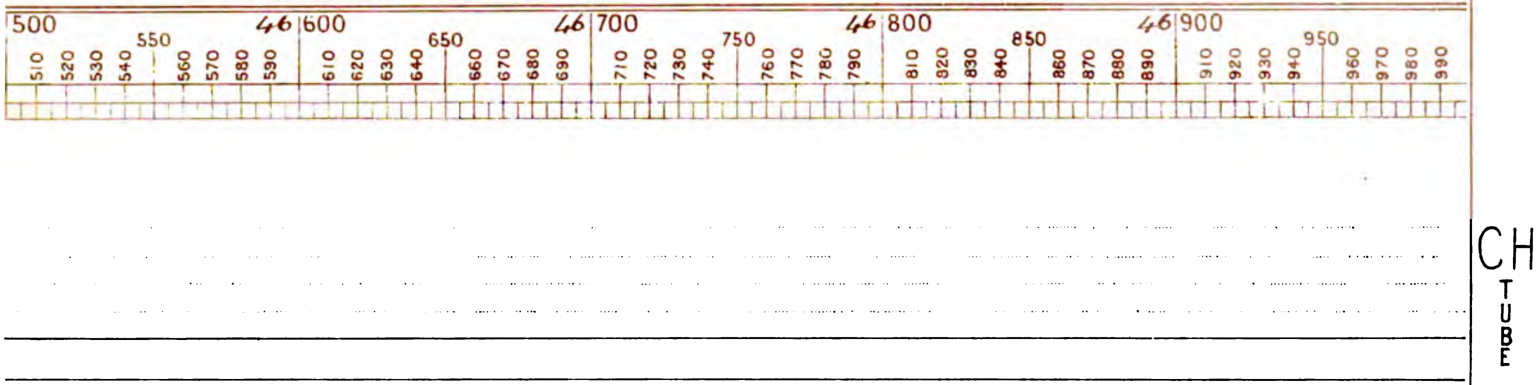
*C.P.S. obs. & del. 1.*

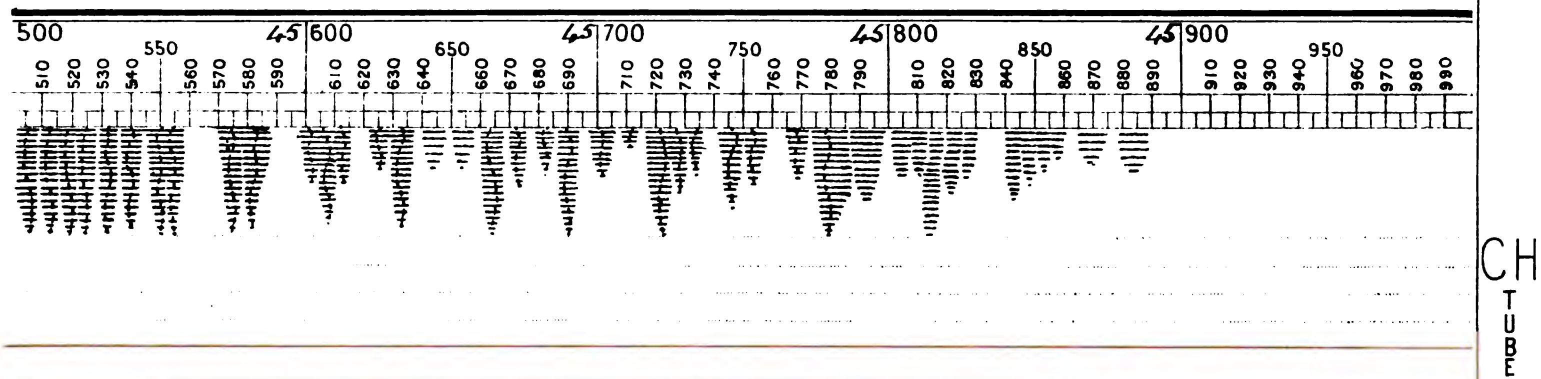
*A. Ritchie & Son.*

# CUUM - TUBE

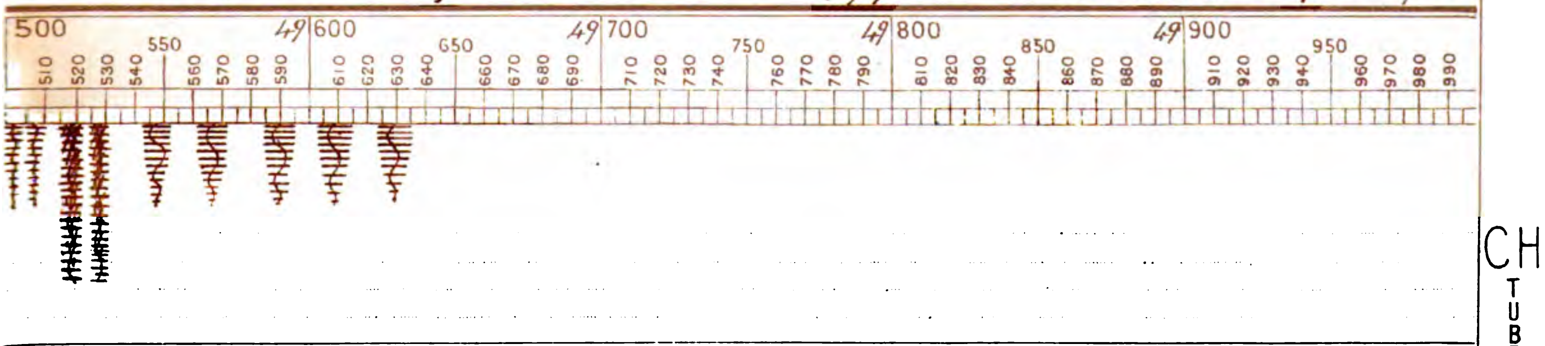



*Prismatic Dispersion = 48° A to H Magnifying power = 12. Quantity*



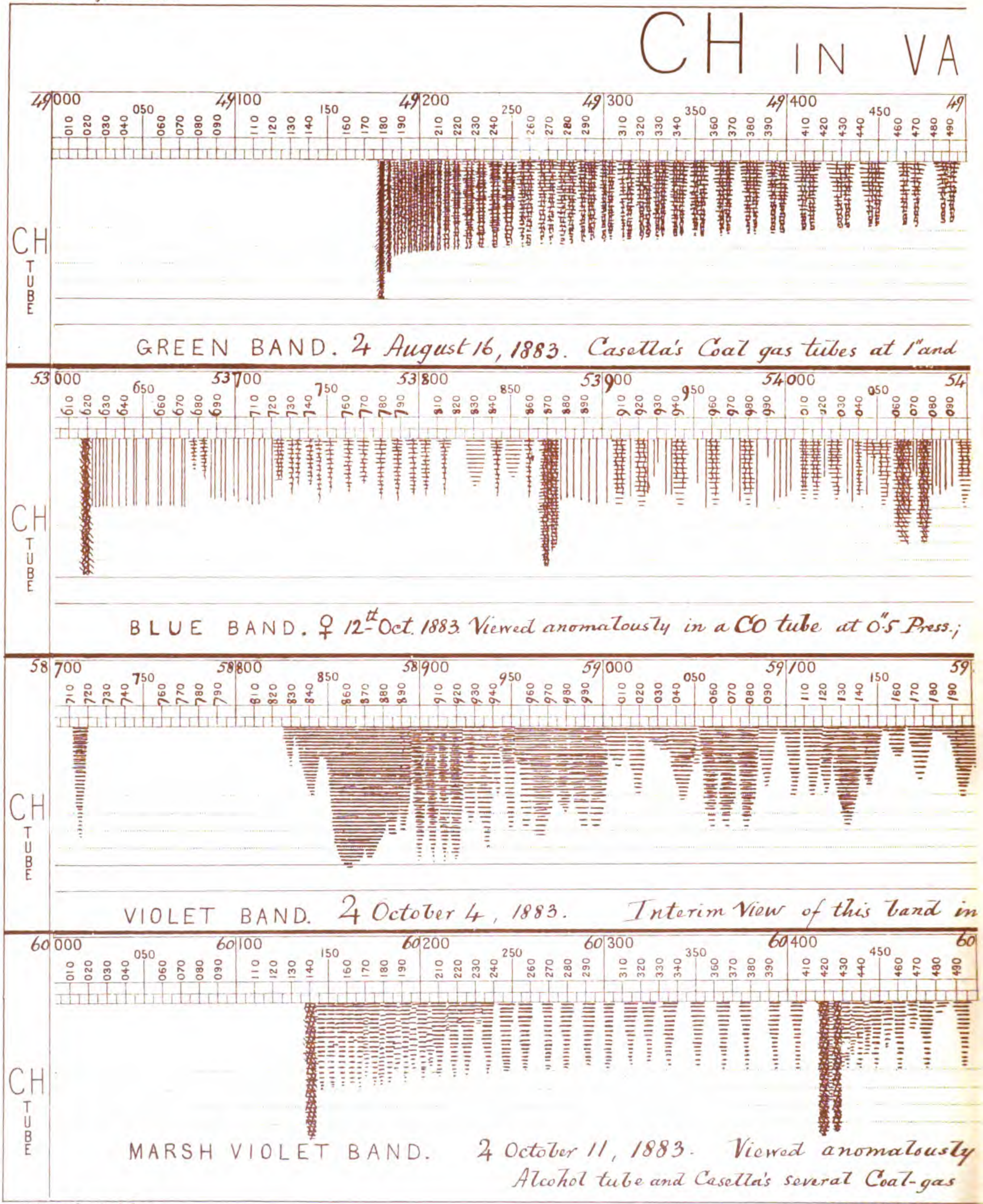




*tube Prismatic Dispersion = 60° A to H. Mag. power = 12 and 21. Intensity Primary in Coil*



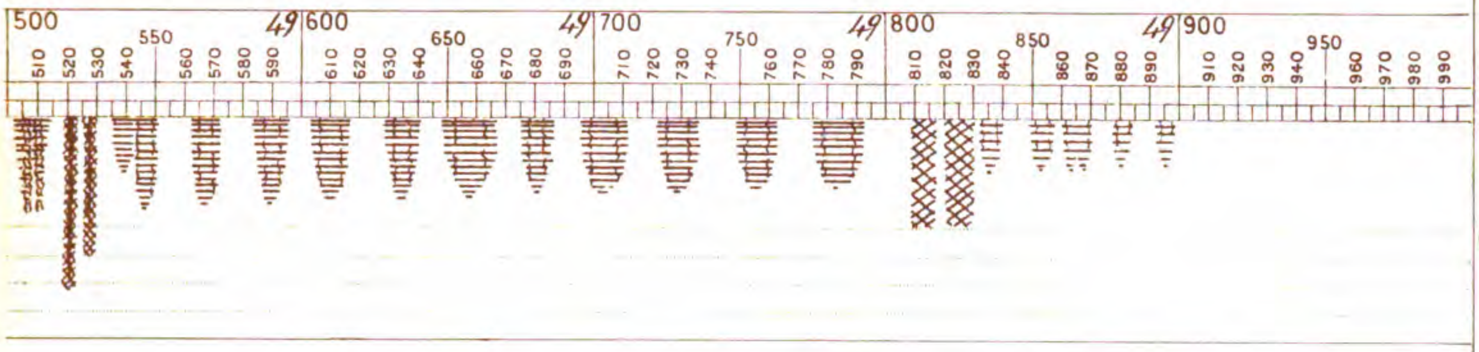

*Viewed in Prof Rowland's Grating. 5th order. Quantity Primary. App's Coil.*

Photo-Lith. 1884. T. H. del. 2.



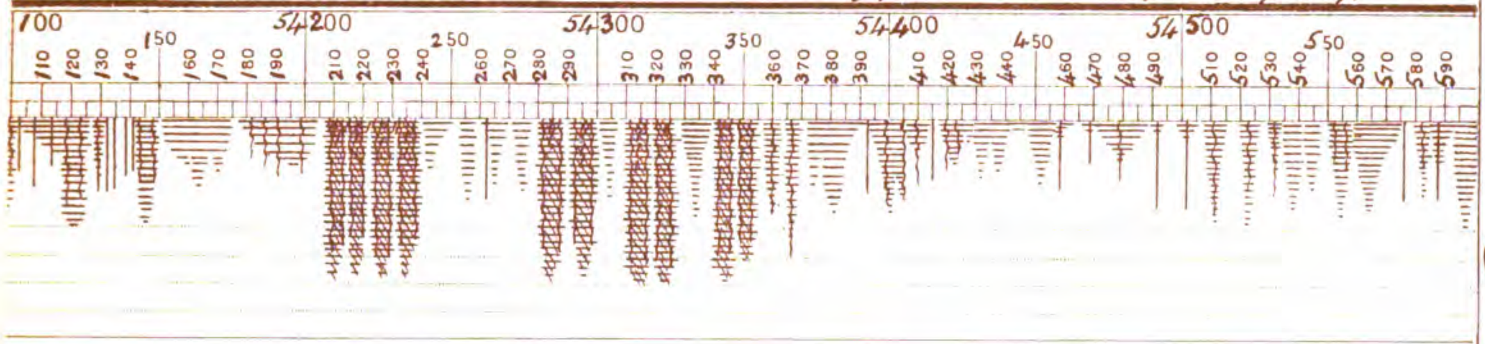

C.P.S. obs. & del. 1. A. Ritchie & Son.

# CUUM - TUBE



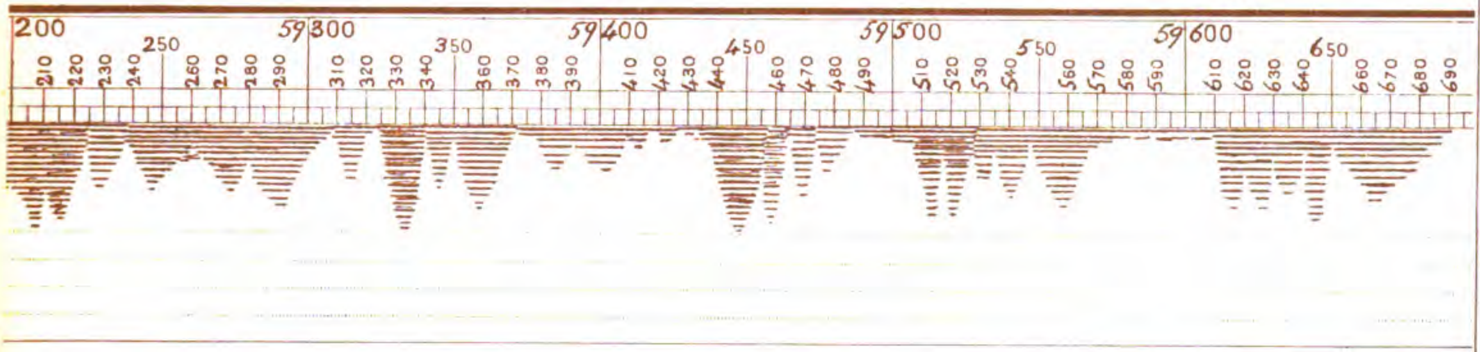

CH TUBE

*5" Pressure. Prismatic Dispersion = 60° A to H. Mag.t power = 12. Intensity Primary in App's Coil.*



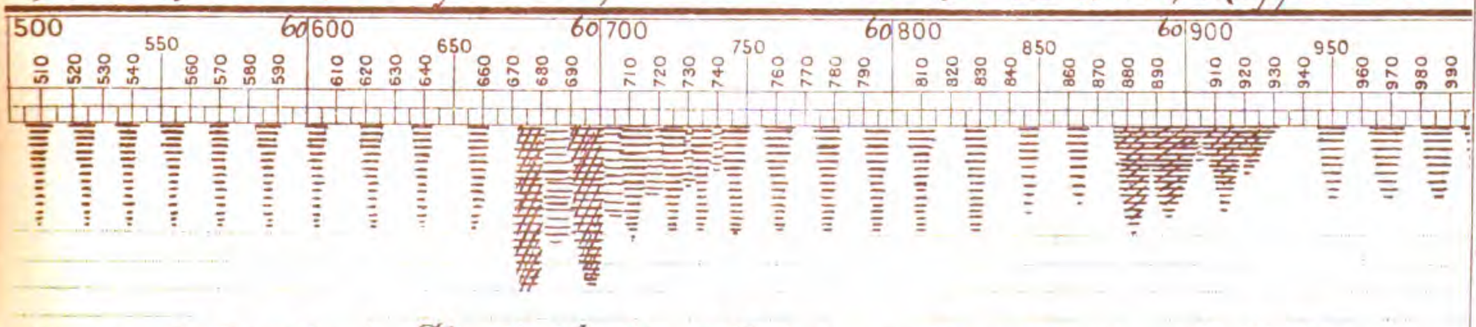

CH TUBE

*but with reference to Alcohol and Coalgas tubes. Prism.tic Dispersion = 48° A to H, Mag. power = 21.*




CH TUBE

*perishing Alcohol, Coal-gas and Olefiant tubes Prism. Disp. = 36° A to H, Mag. power = 21.*



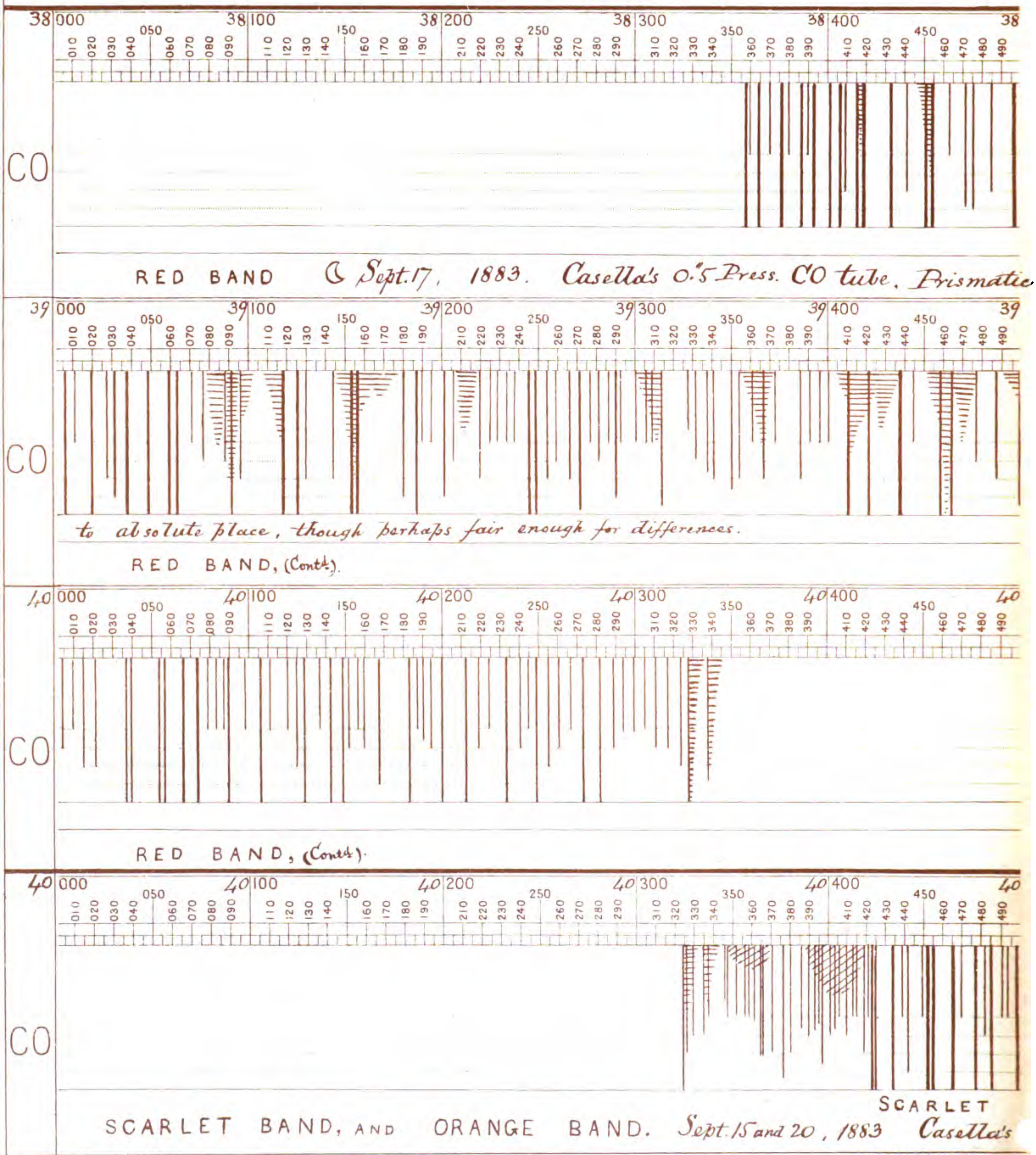

CH TUBE

*as an impurity in Sharp's 0·5 Press.re H tube, and compared with Salleron's tubes. Prismatic Dispersion = 36° A to H; Mag. power = 21.*

*Photo-lith 1884.*

*T. H. del. 2.*

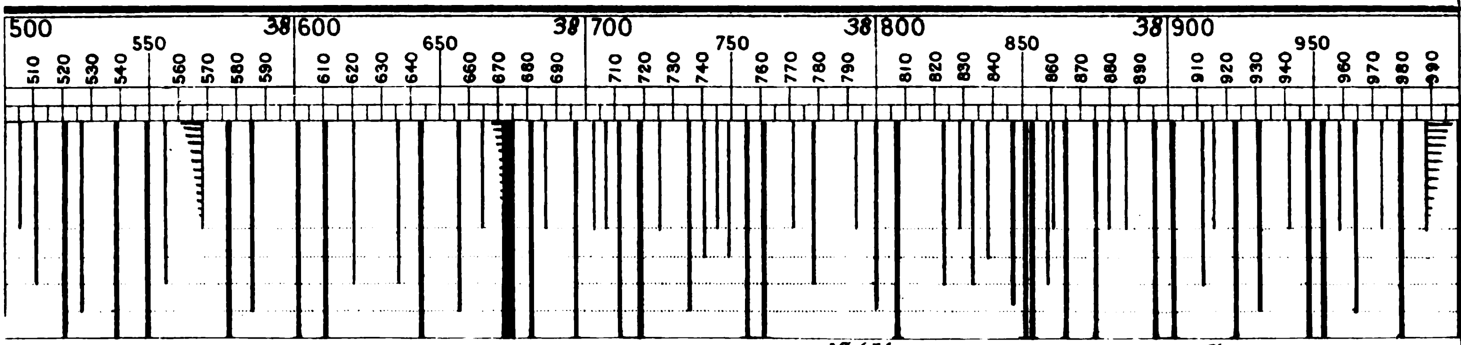
# CO IN VA




C. P. S. obs. & del. 1.

A. Ritchie & Son,

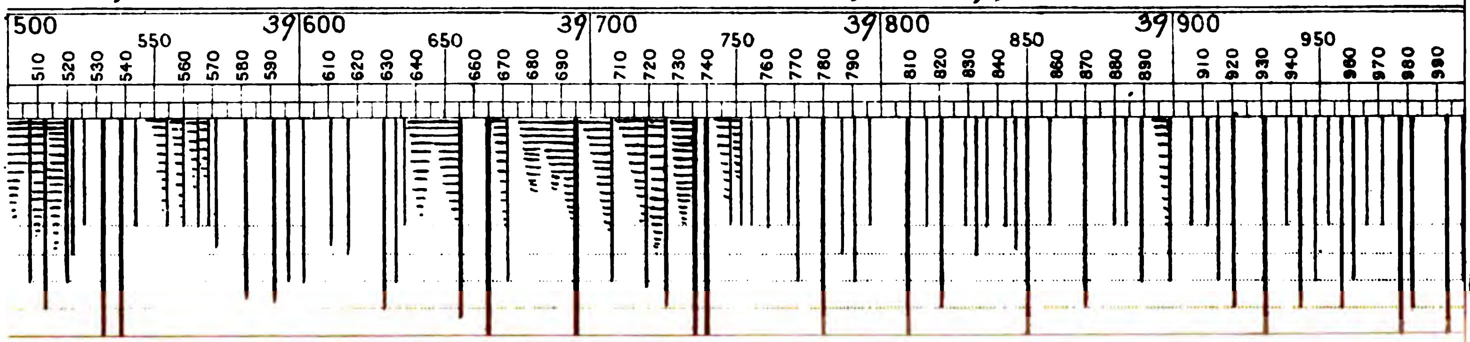
# -CUUM -TUBE



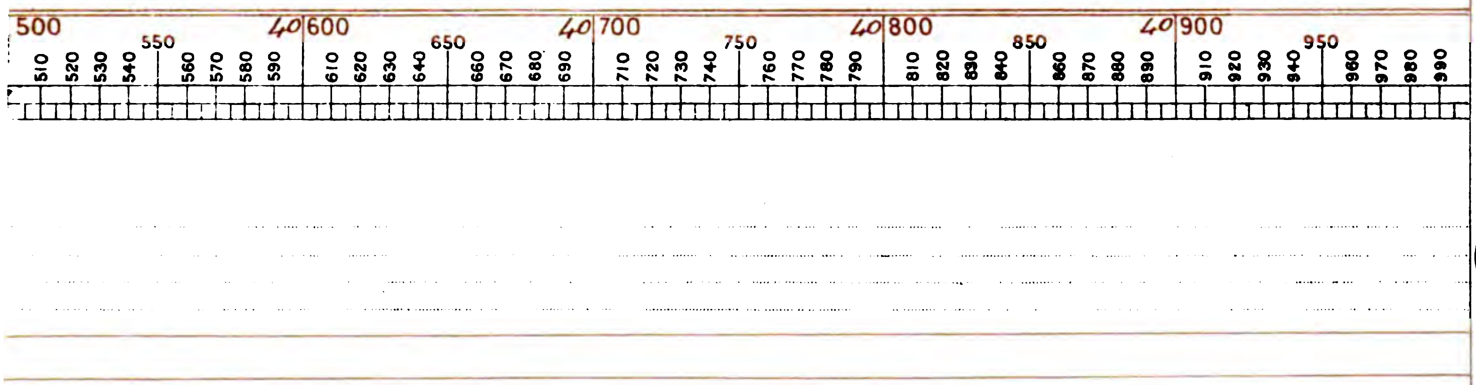

CO

RED H coming in here, 38.674 and not at 38 707. shows Scale in error as

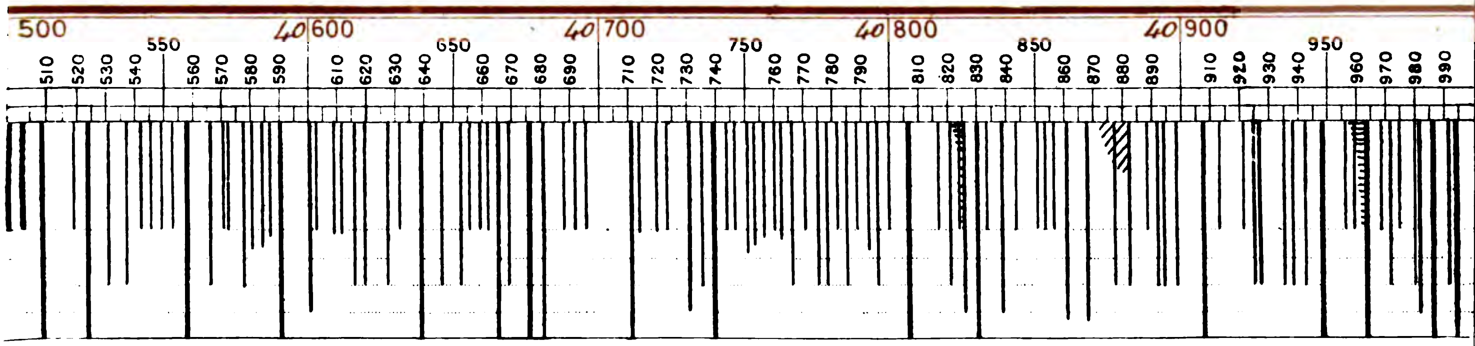
: Dispersion = 60° A-to H. Quantity Primary in App Coil.




CO




CO



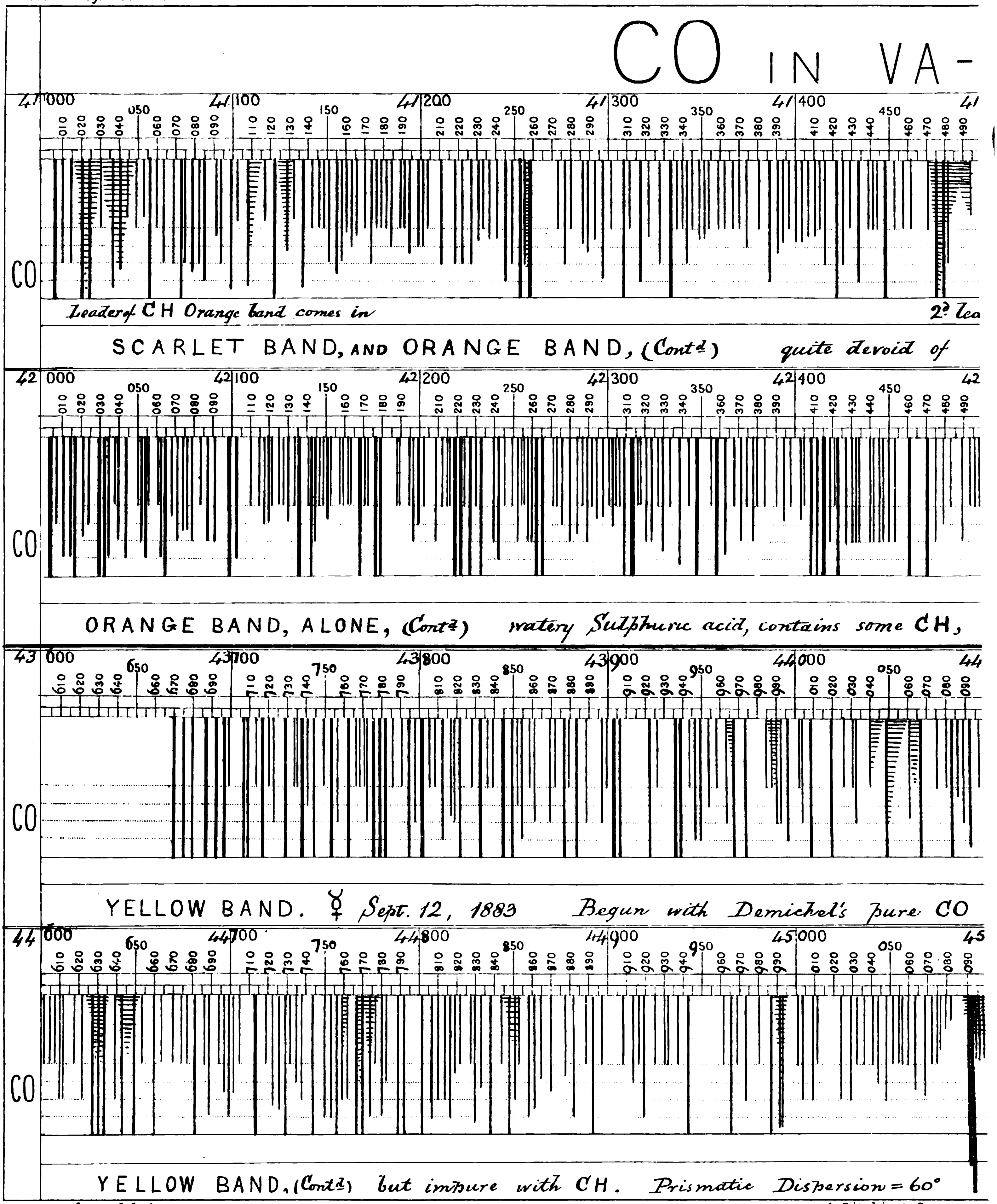

CO

BAND.

tubes of CO at 0·5 and 2·5 Pressure, also Demichel's CO tubes which are

Photo-lith. 1884.

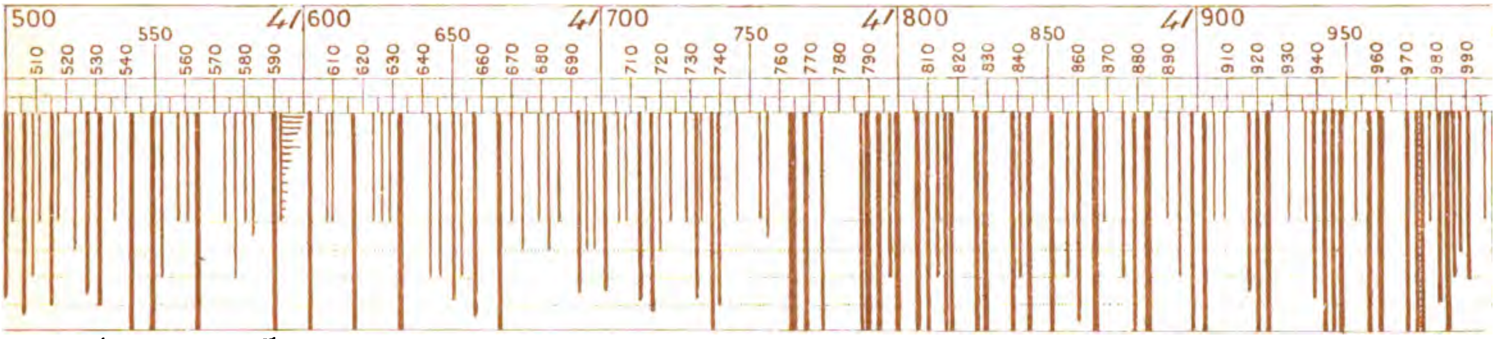
T H. del. 2.




C.P.S. obs. & del. I.

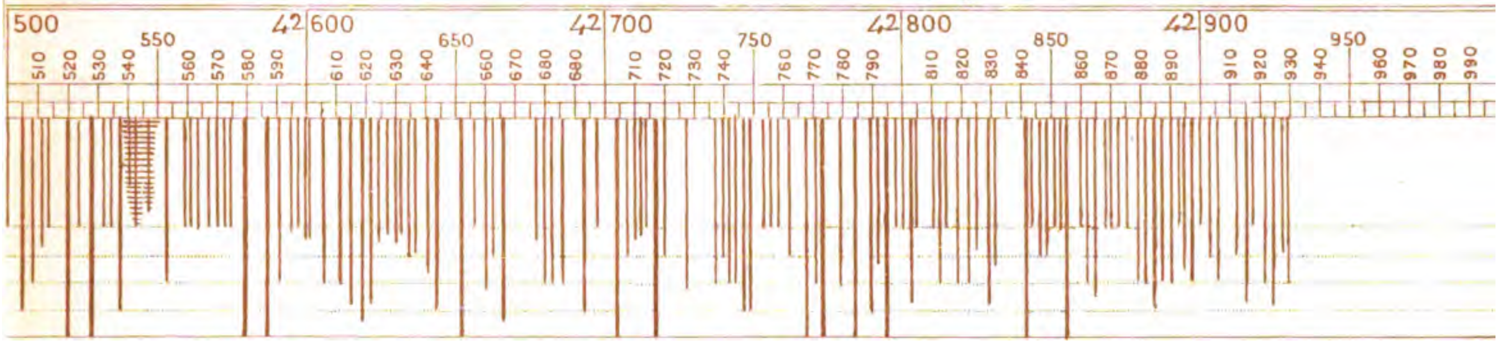
A. Ritchie & Son.

# -CUUM-TUBE

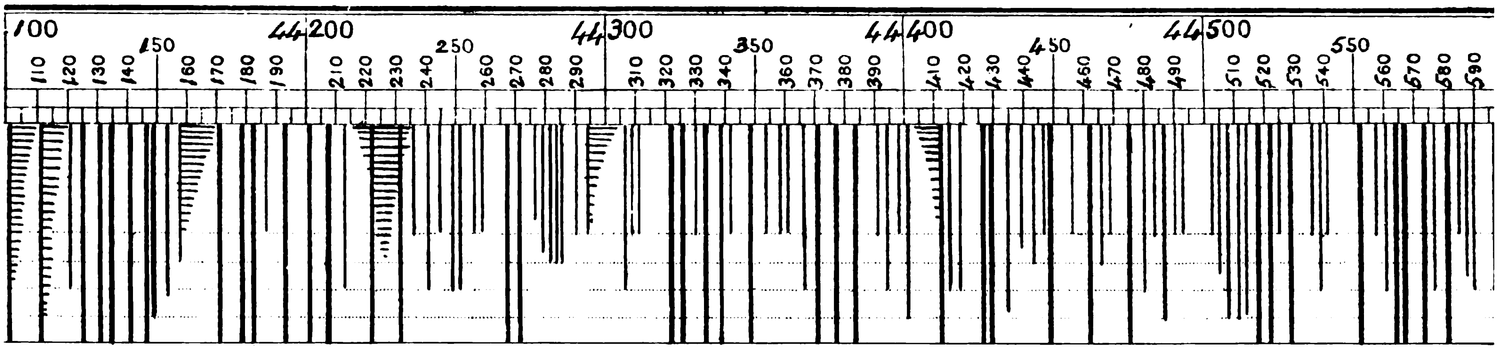



-der of CH Orange band comes in. ORANGE BAND OF CO.

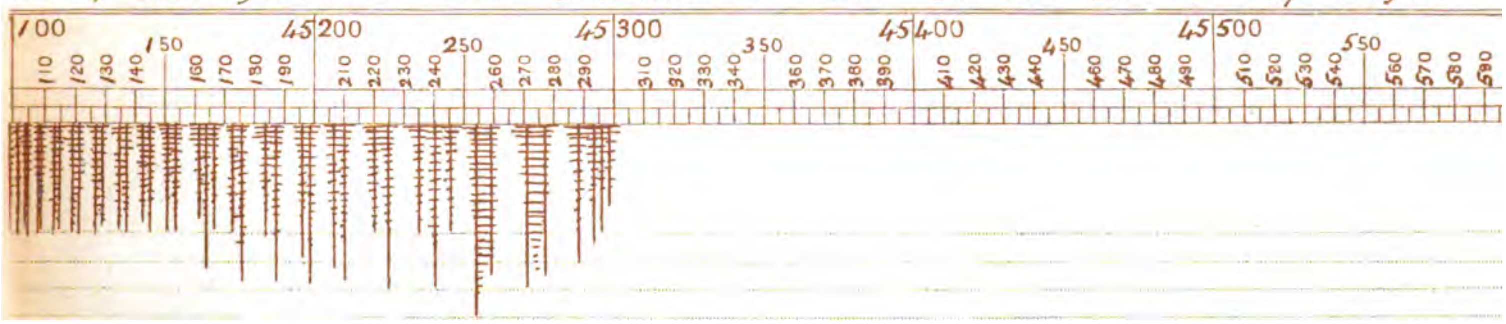
all impurities either of H or CH. Casella's CO, prepared with weak,




but no H, impurities. Prismatic Dispersion = 60° A to H. Mag.y power = 21.



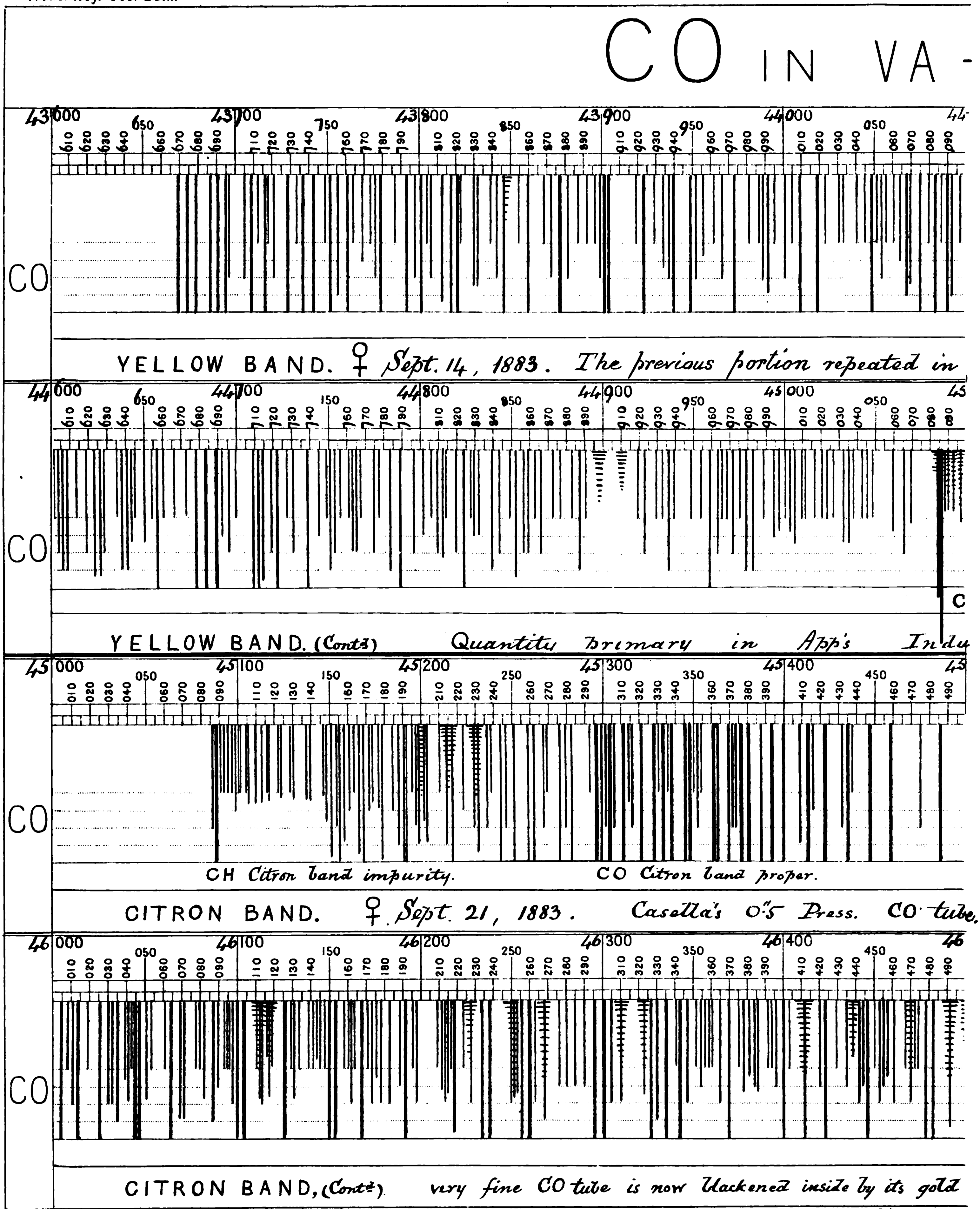

tube; and finished with Casella's CO tube at 0"5 Press. very bright




CH Citron band impurity.

Mag. power = 21. Quantity Primary in Abb's Induction Coil

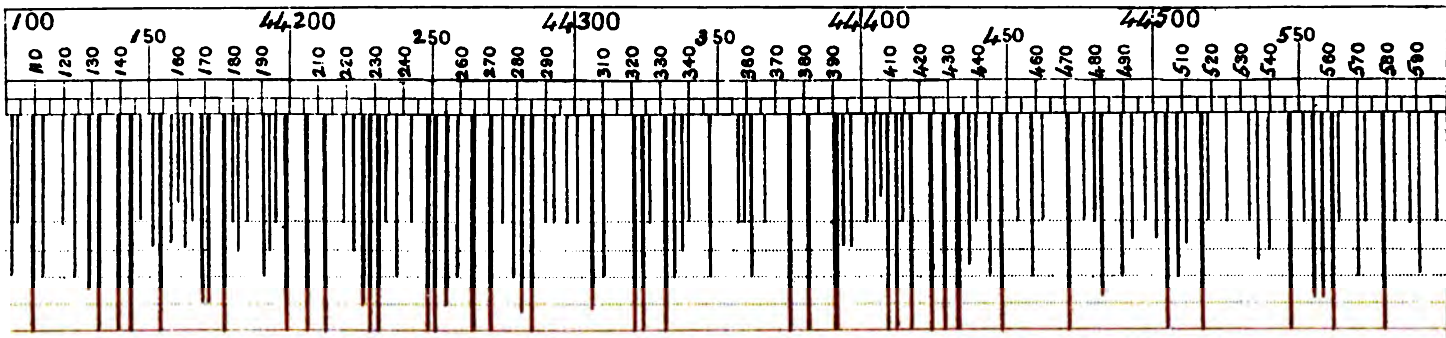
Photo-Lith. 1884. T. H. de




C.P.S. obs. & del. I.

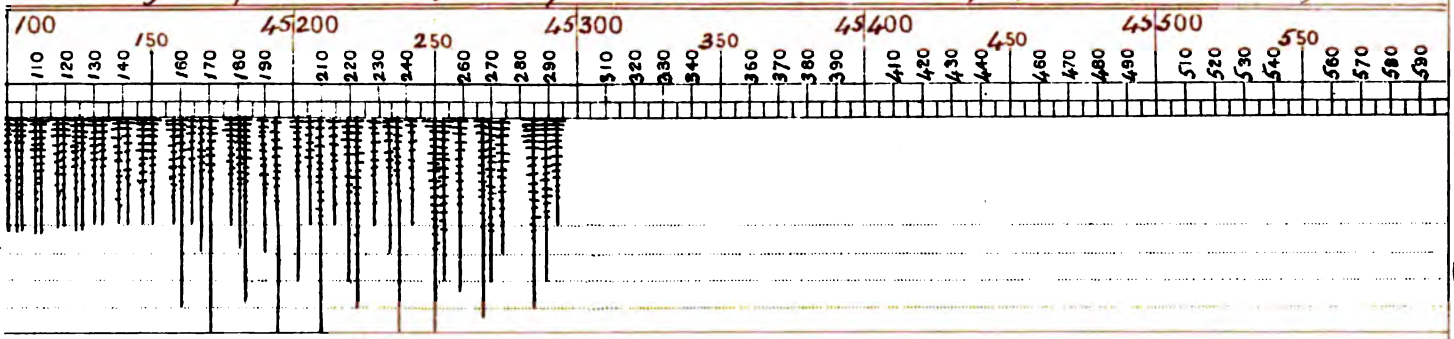
A. Ritchie & Son.

# -CUUM-TUBE



CO

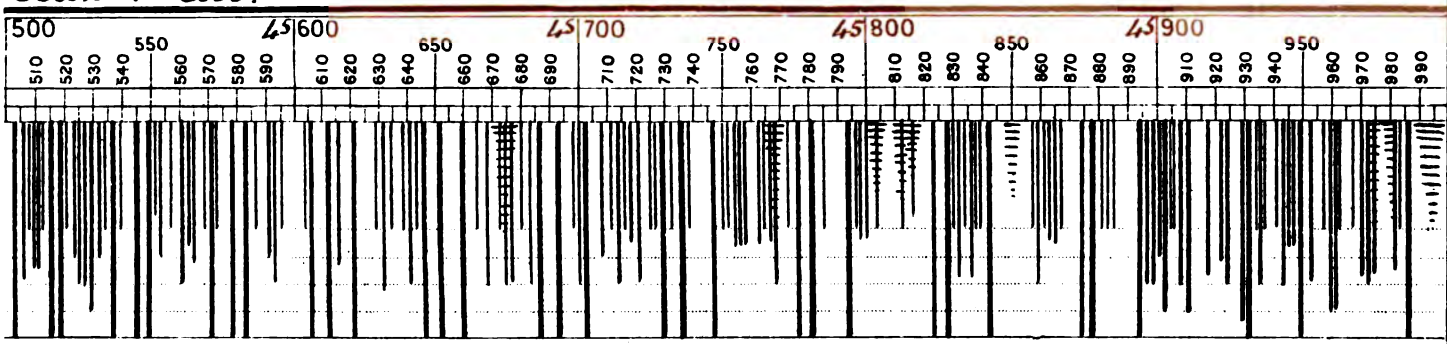
every particular, except with Intensity, in place of



CO

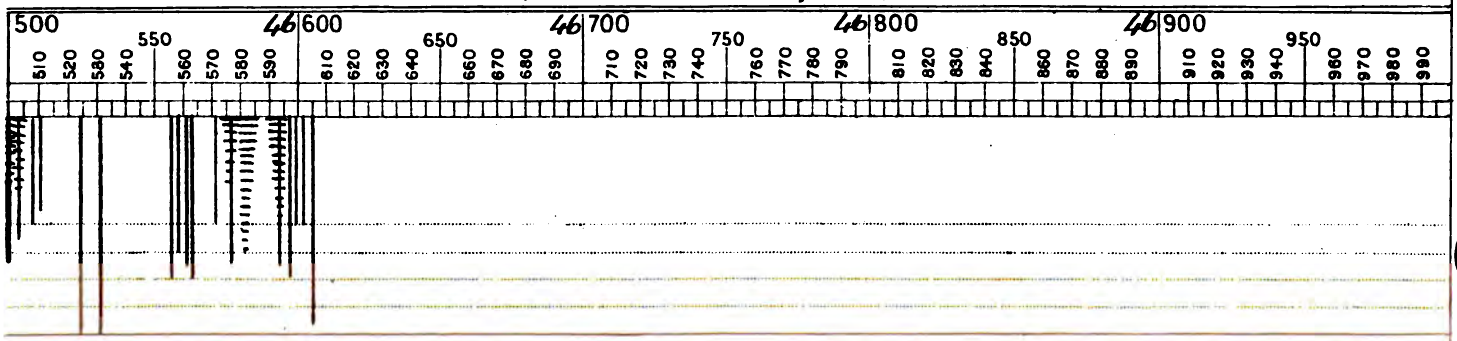
H Citron band impurity.

ction. Coil.



CO

and his $CO + CO^2$ tube at Press. 0".2 and nearly free of CH impurity Demichel's

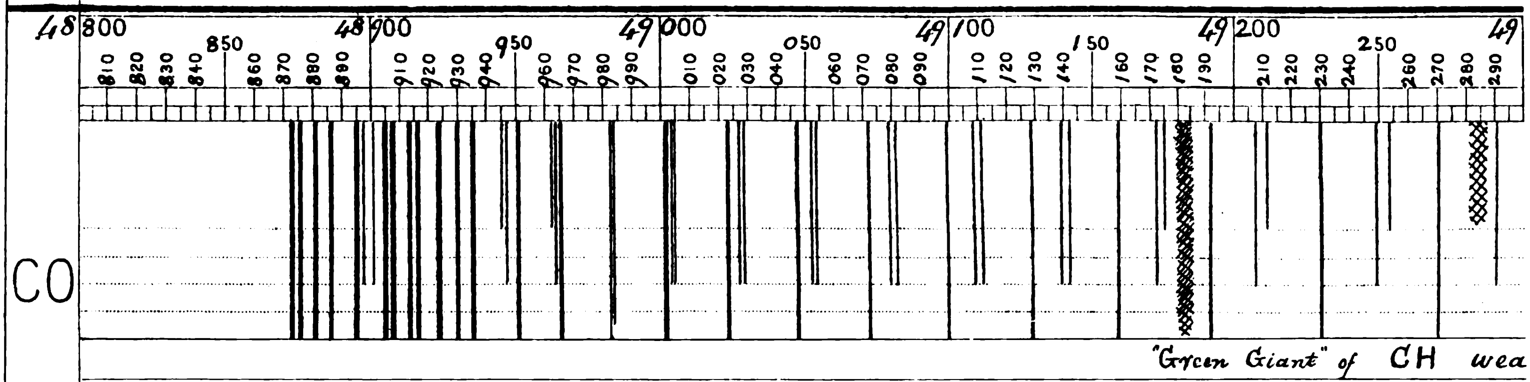


CO

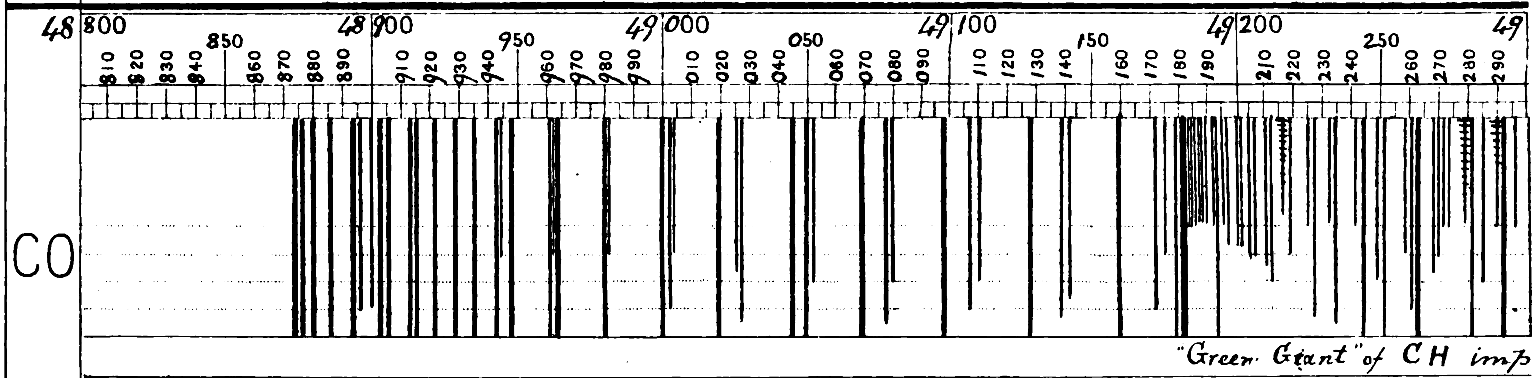
electrodes. Prismatic Dispersion = 60° A to H. Mag. power = ·21.

Photo-Lith. 1884. T. H. del. 2.

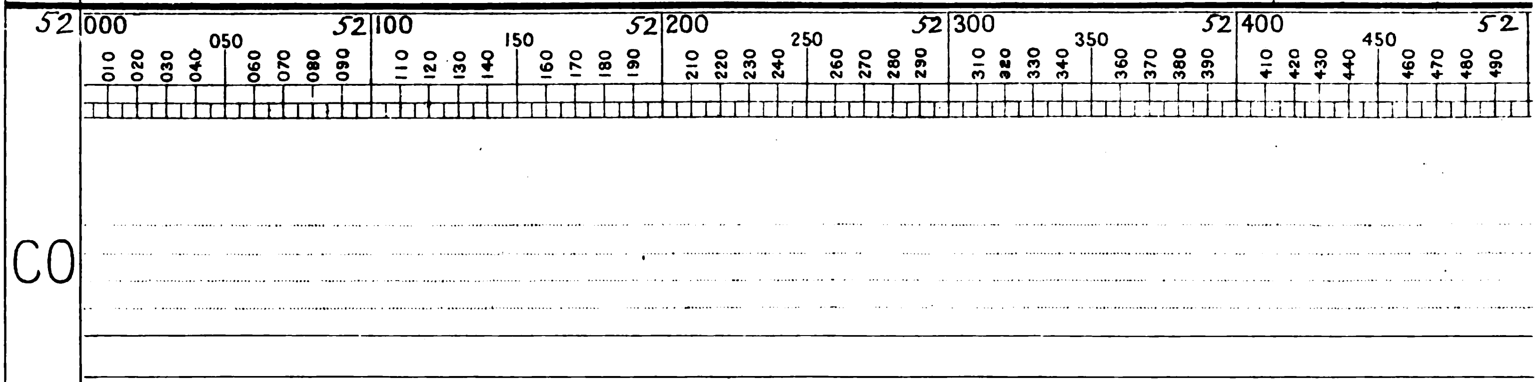
# CO IN VA-



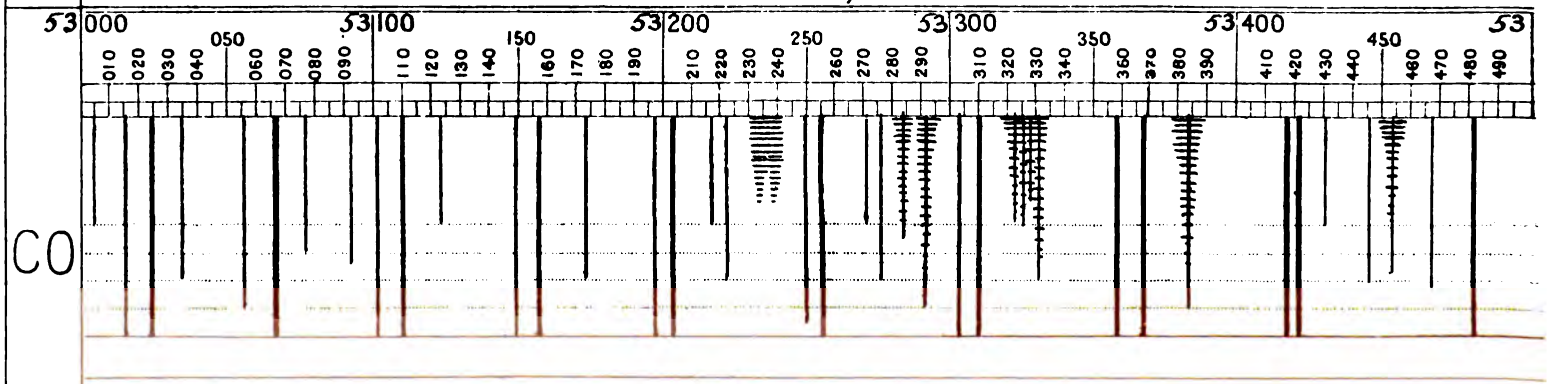

GREEN BAND. ♀ Aug. 10, 1883. Casella's CO tube at 0.1 Pressure.




GREEN BAND. ☾ Sept. 24, 1883. Green CO intruded into by Green CH, in




BLUE BAND ♃ Sept. 27, 1883. Casella's 0.5 Press.




BLUE BAND, 1 (Contd.) — primary.

# -CUUM - TUBE

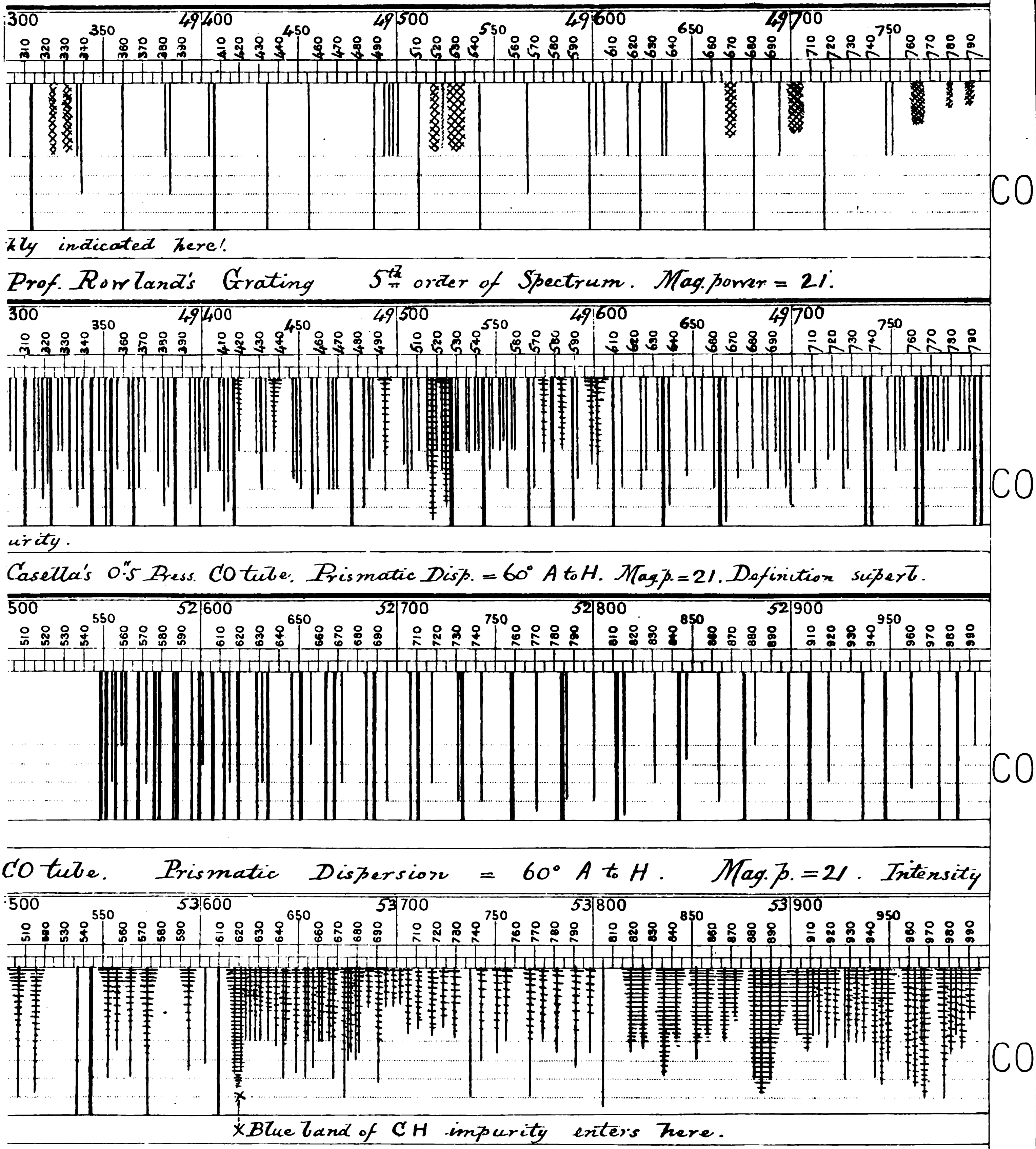
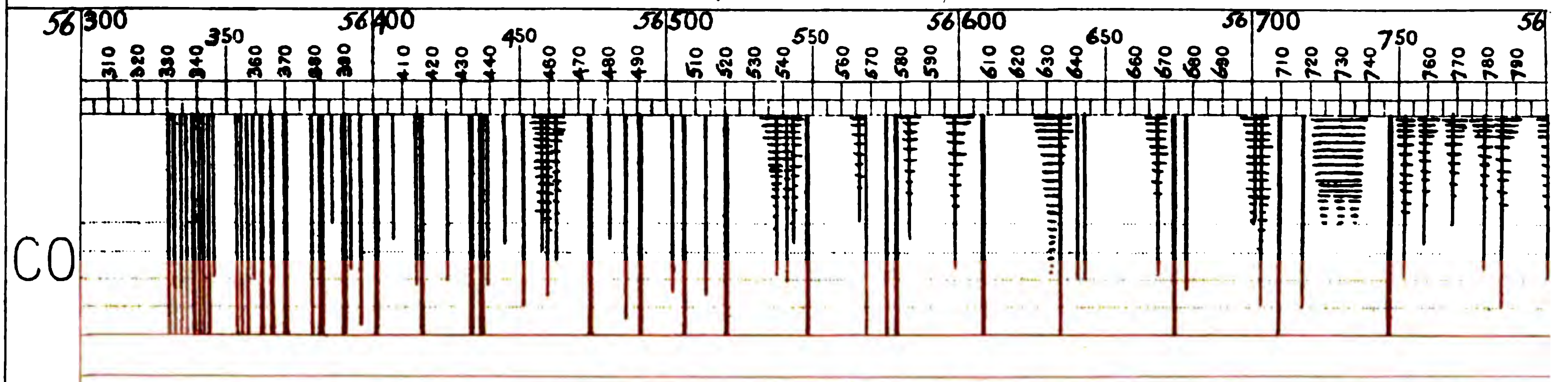


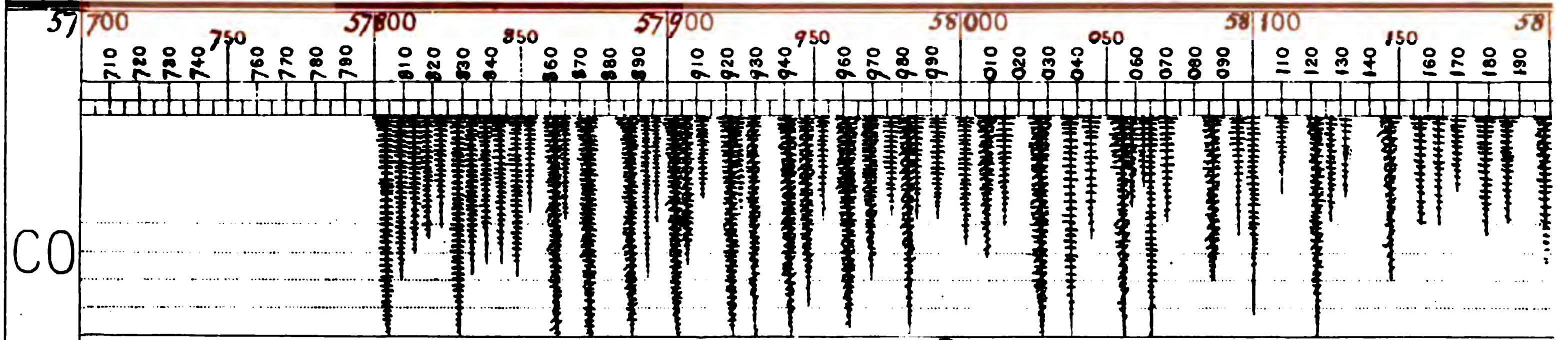

Photo-lith. 1884.

T H. del. 2

# CO IN VA-

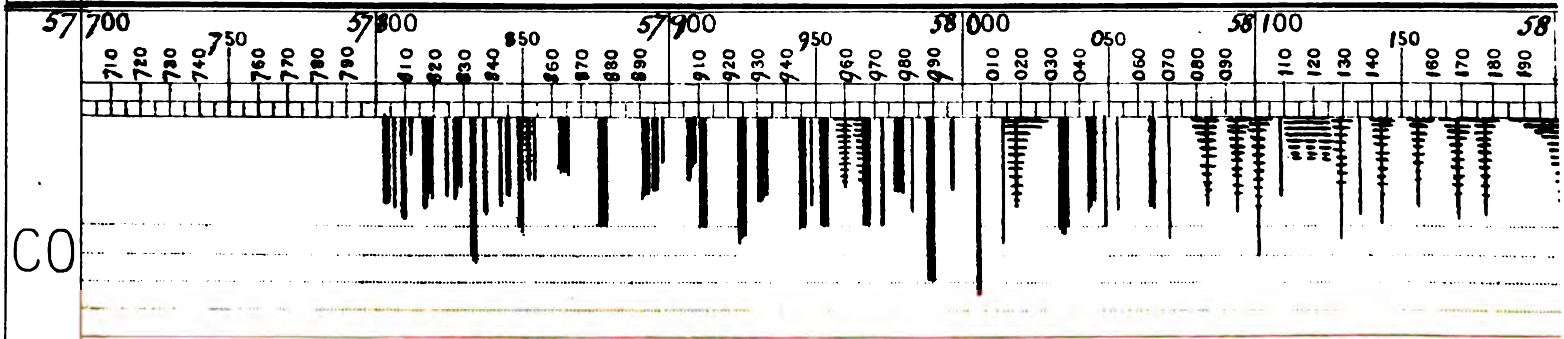



INDIGO BAND. ♄ *Sept. 29, 1883 Casella's 0·2 Press. tube of CO.*




*Definition of violet lines cannot be obtained.*

VIOLET BAND. ♄ *Sept, 1, 1883. Demichel's CO tube, also Casella's CO tubes, his O*



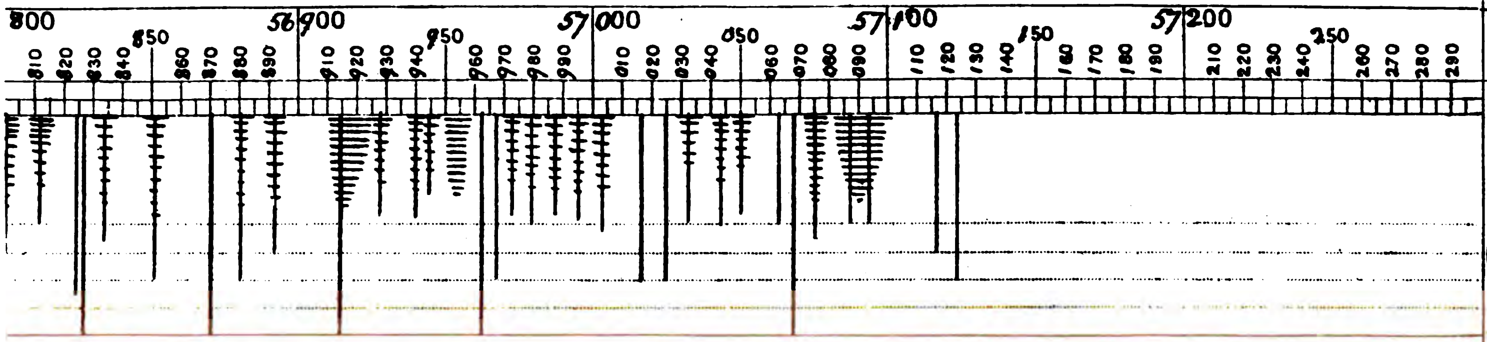

*Definition a little better at beginning, but falls off rapid*

VIOLET BAND. ☾ *October 1, 1883. Above repeated with same tubes, but*

CO

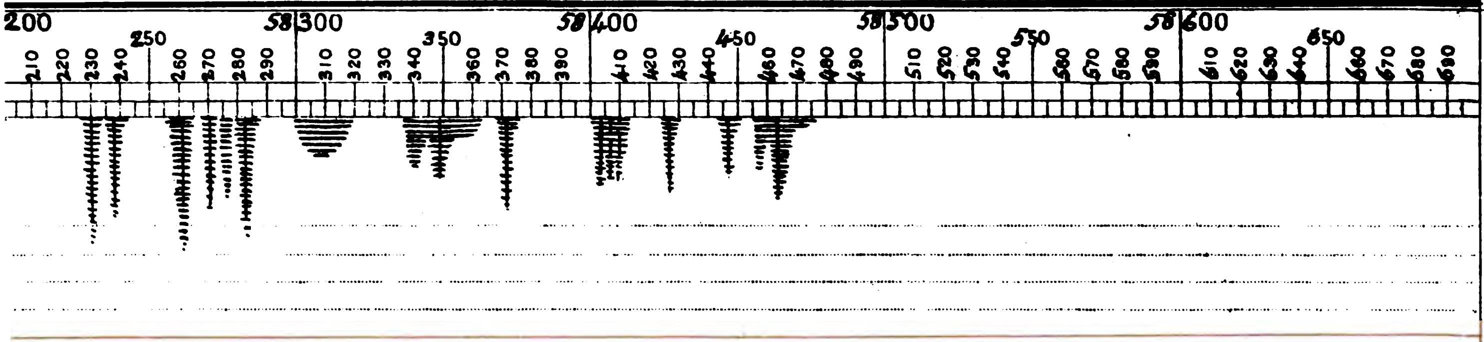
*C.P.S. obs. & del. 1.* *A. Ritchie & Son.*

# -CUUM-TUBE



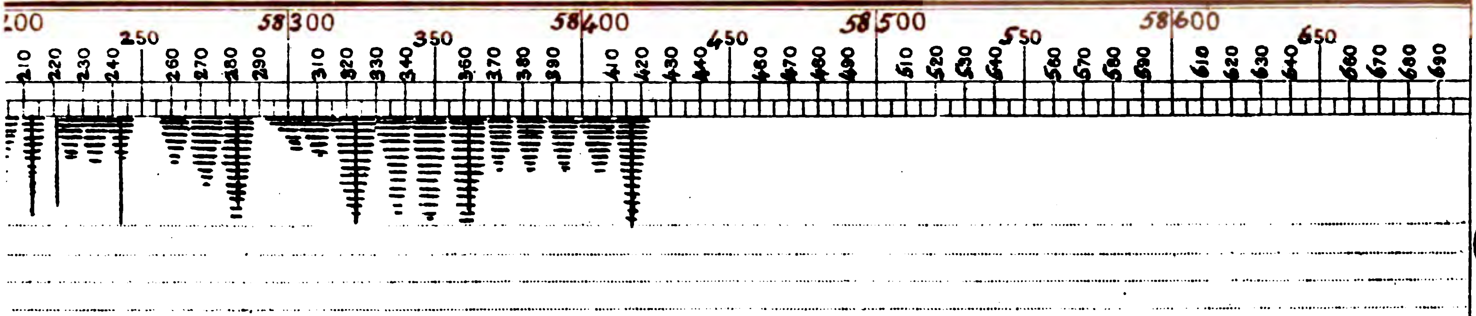
CO

*Prismatic Dispersion = 48° A to H, Mag. power = 21. Lines difficult and becoming hazy.*



CO

*tube at 0'1 press. (strong in CO), and his CO+CO² tube at 0"3 Press. Small plates in Battery:*

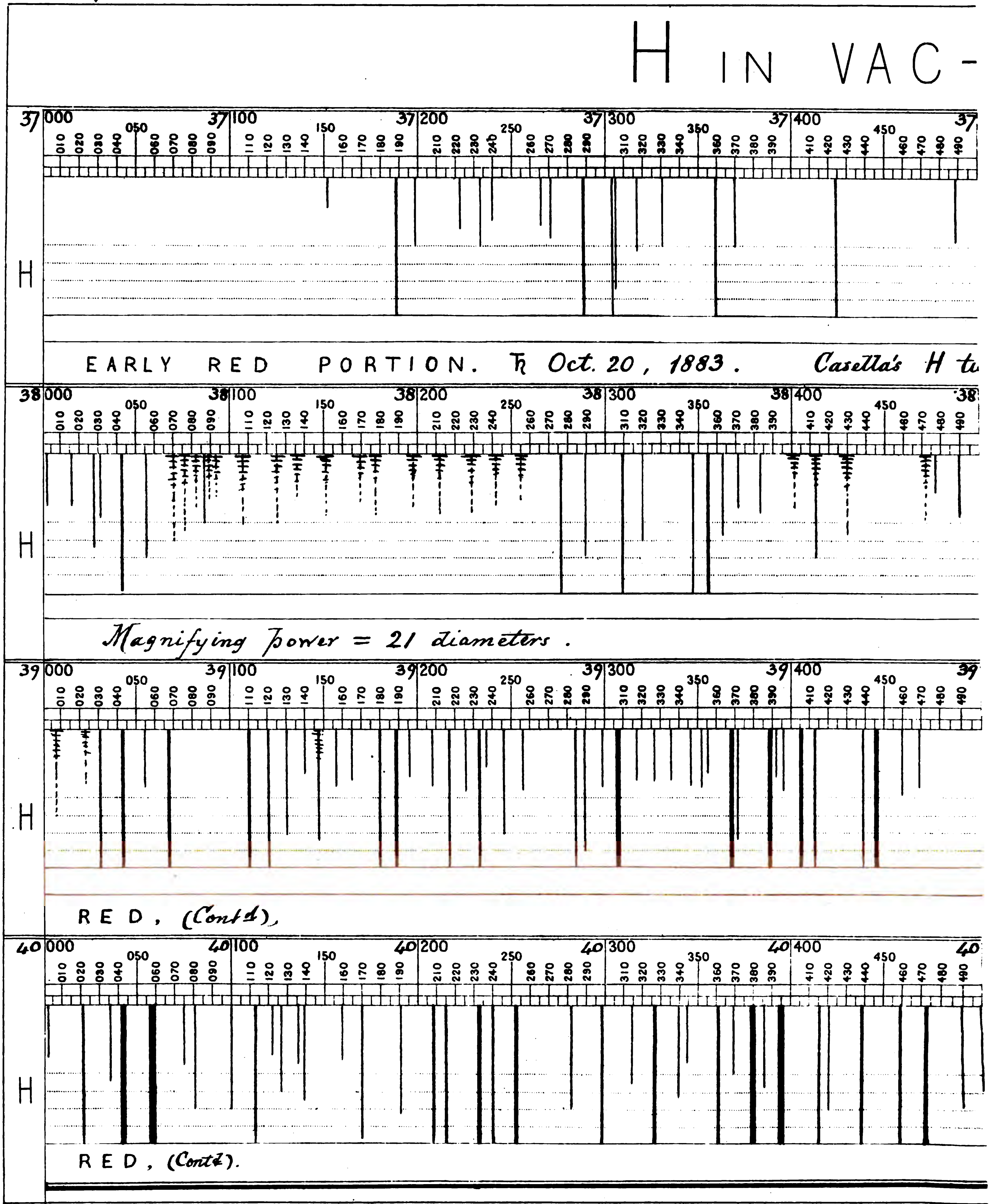


CO

*ly.*

*with larger plates in Battery, & sparks increased from 2" to 3" long. Definition distressingly bad*

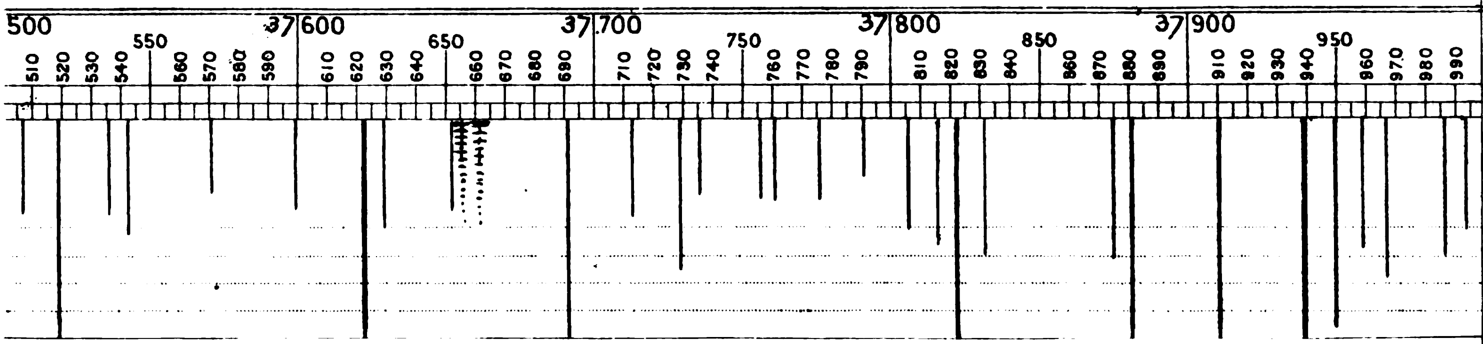
CO



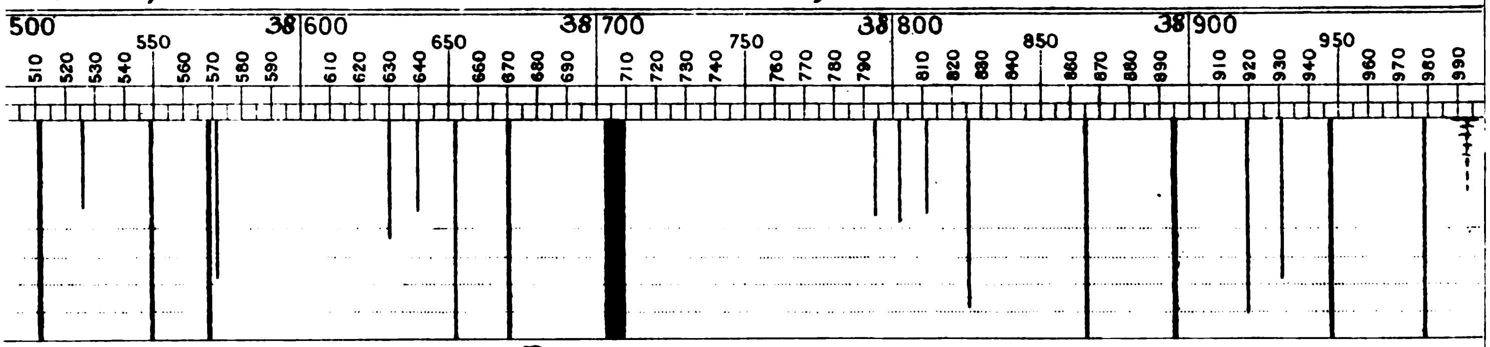

C. P. S. obs. & del. 1.

A. Ritchie & Son,

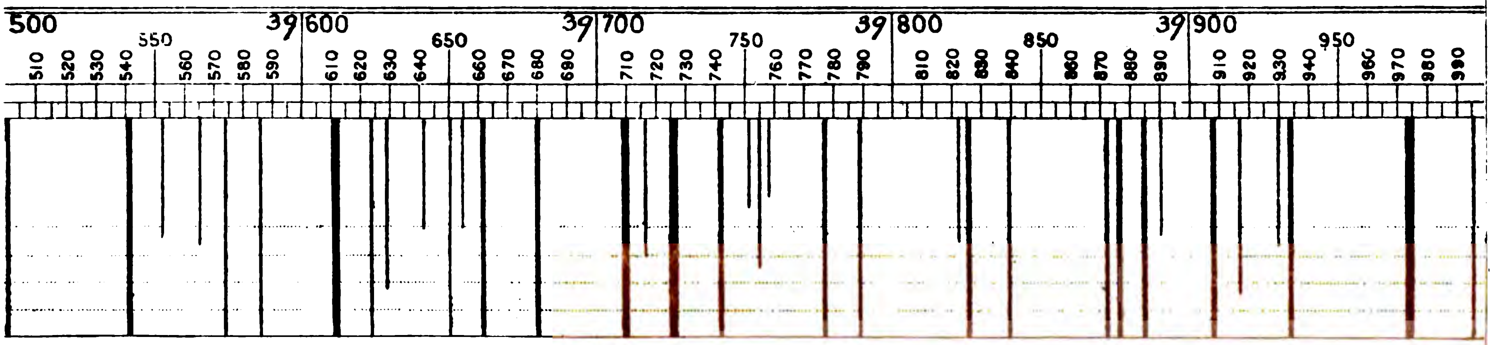
# -UUM - TUBES

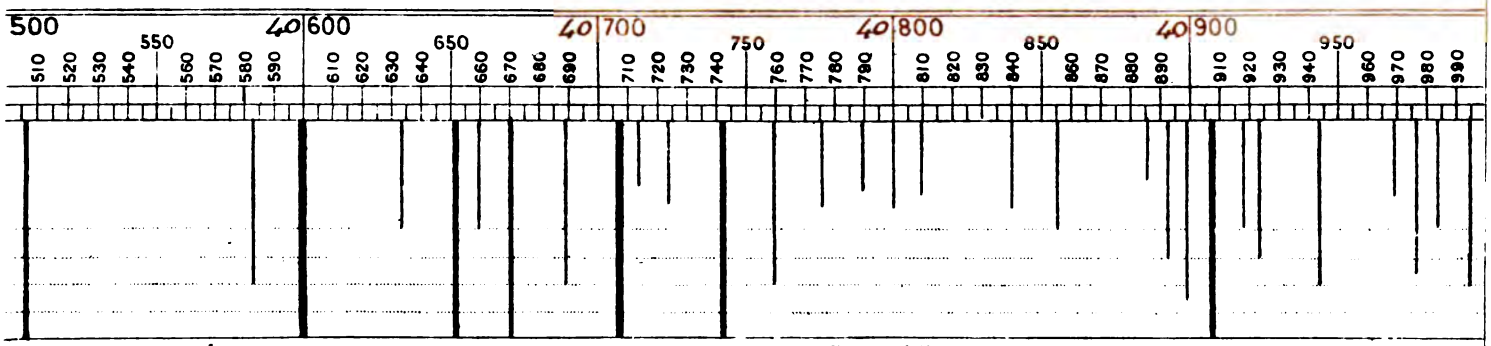



...be, at pressure 0"4. Prismatic Dispersion = 60° A to H.




Red Hydrogen.

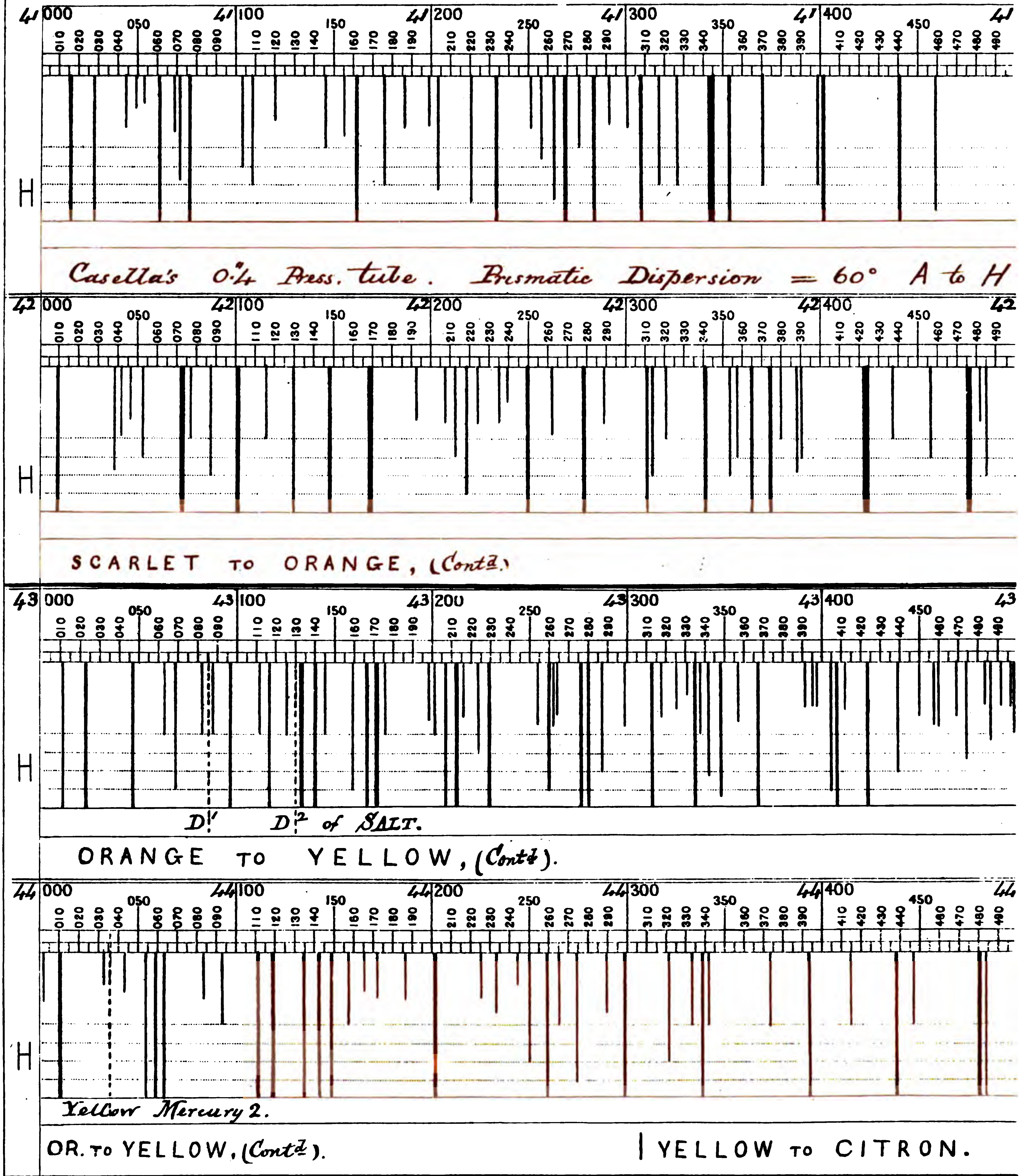



SCARLET TO ORANGE. ♂ 16th October 1883.

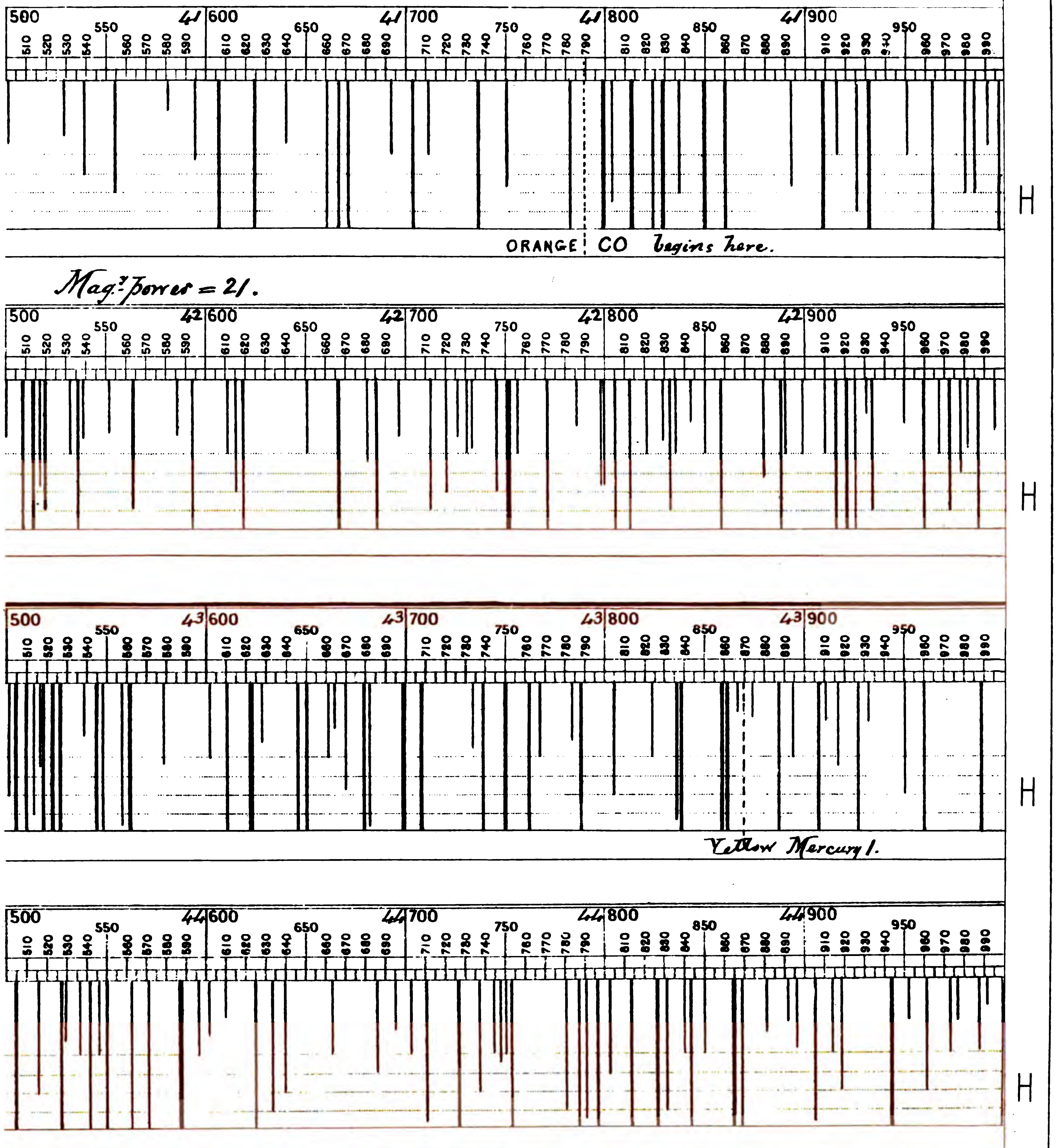
Photo-lith. 1884. T. H. del. 2.

# H IN VAC-




C.P.S. obs. & del. 1. A. Ritchie & Son.

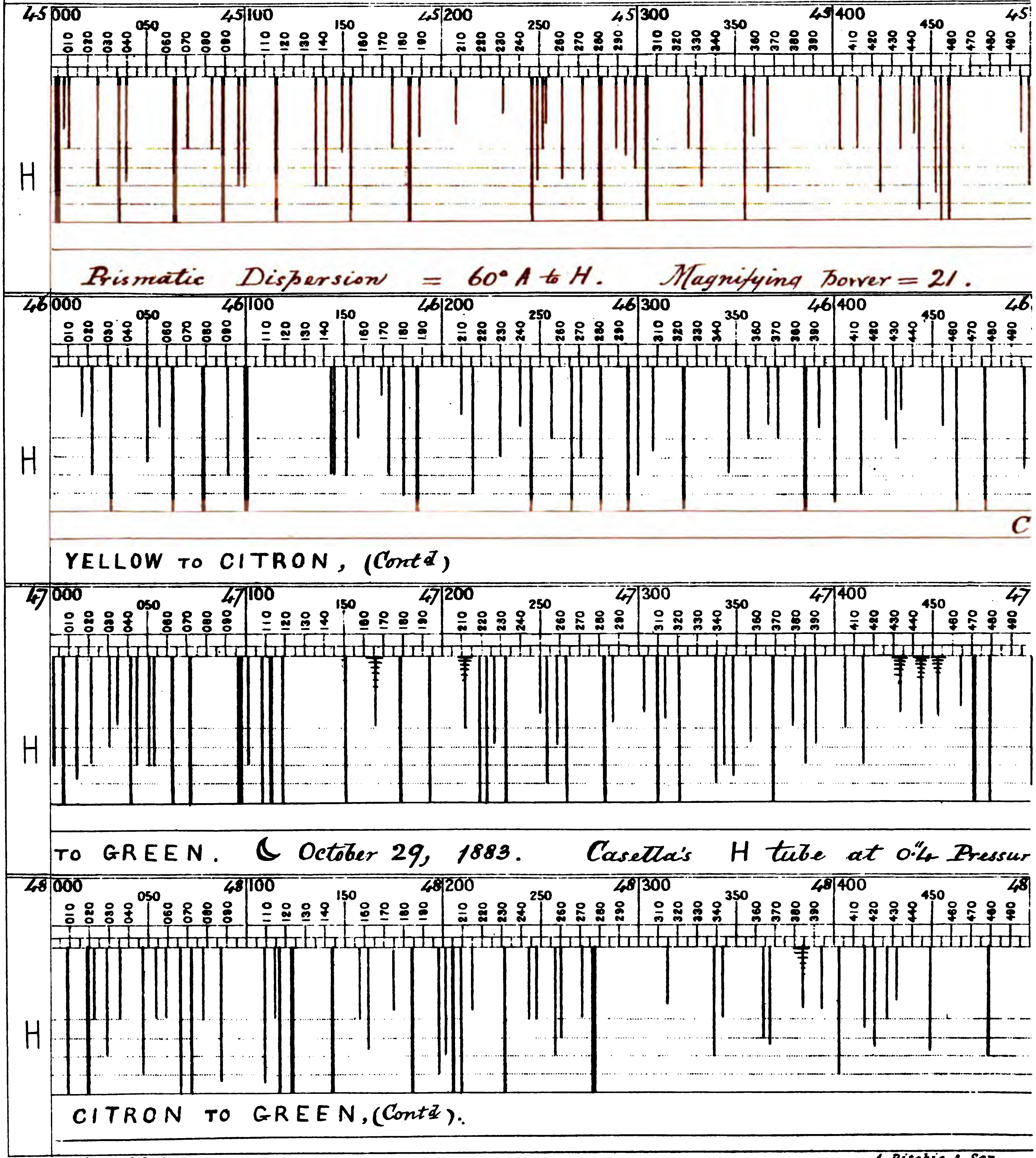
# -UUM - TUBES




2 October 25, 1883. Casella's H tube at 0".4 Pressure.

Photo-lith. 1884. T H. del. 2.

# H IN VAC-




C.P.S. obs. & del. 1

A. Ritchie & Son.

# -UUM - TUBES

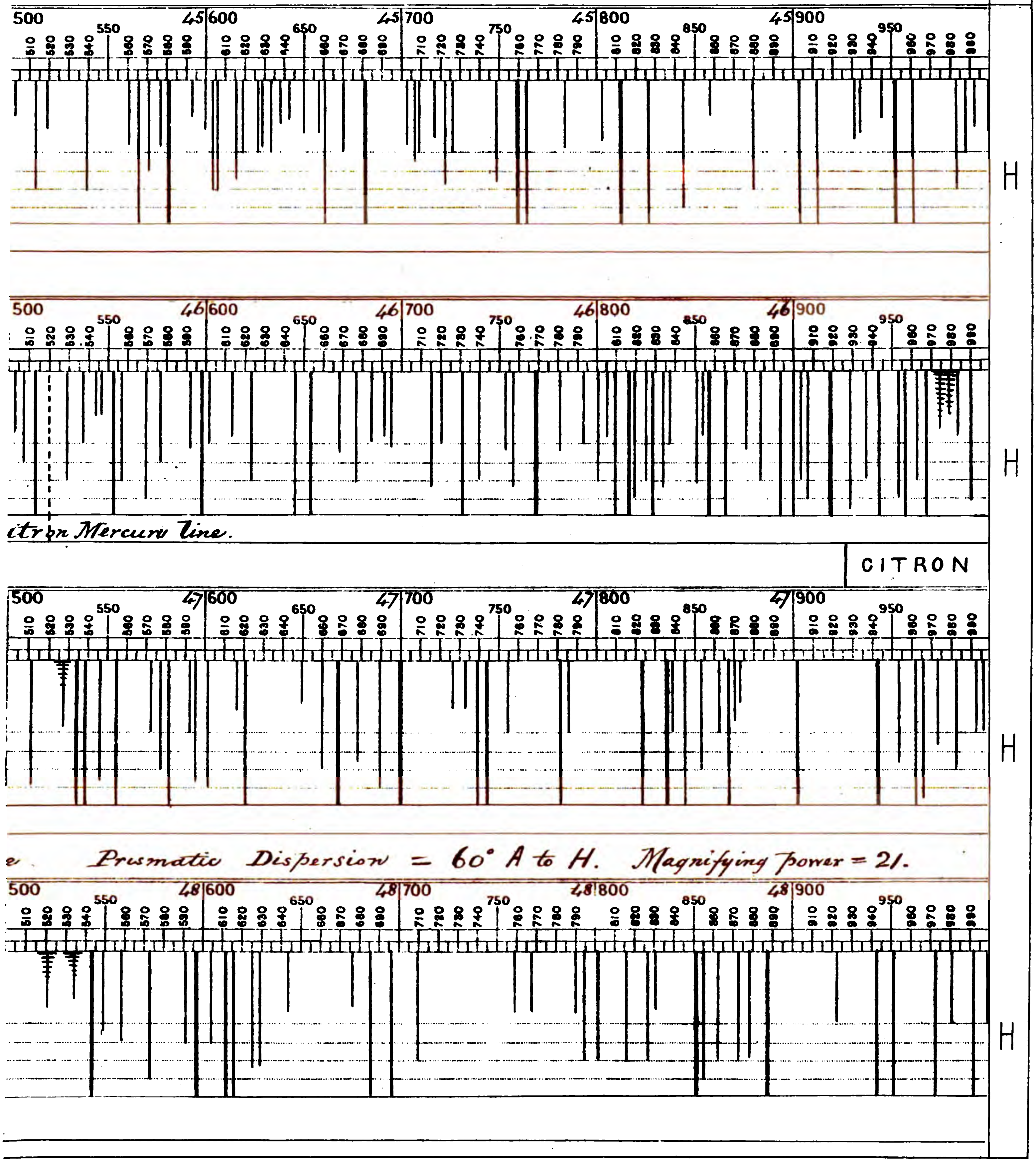
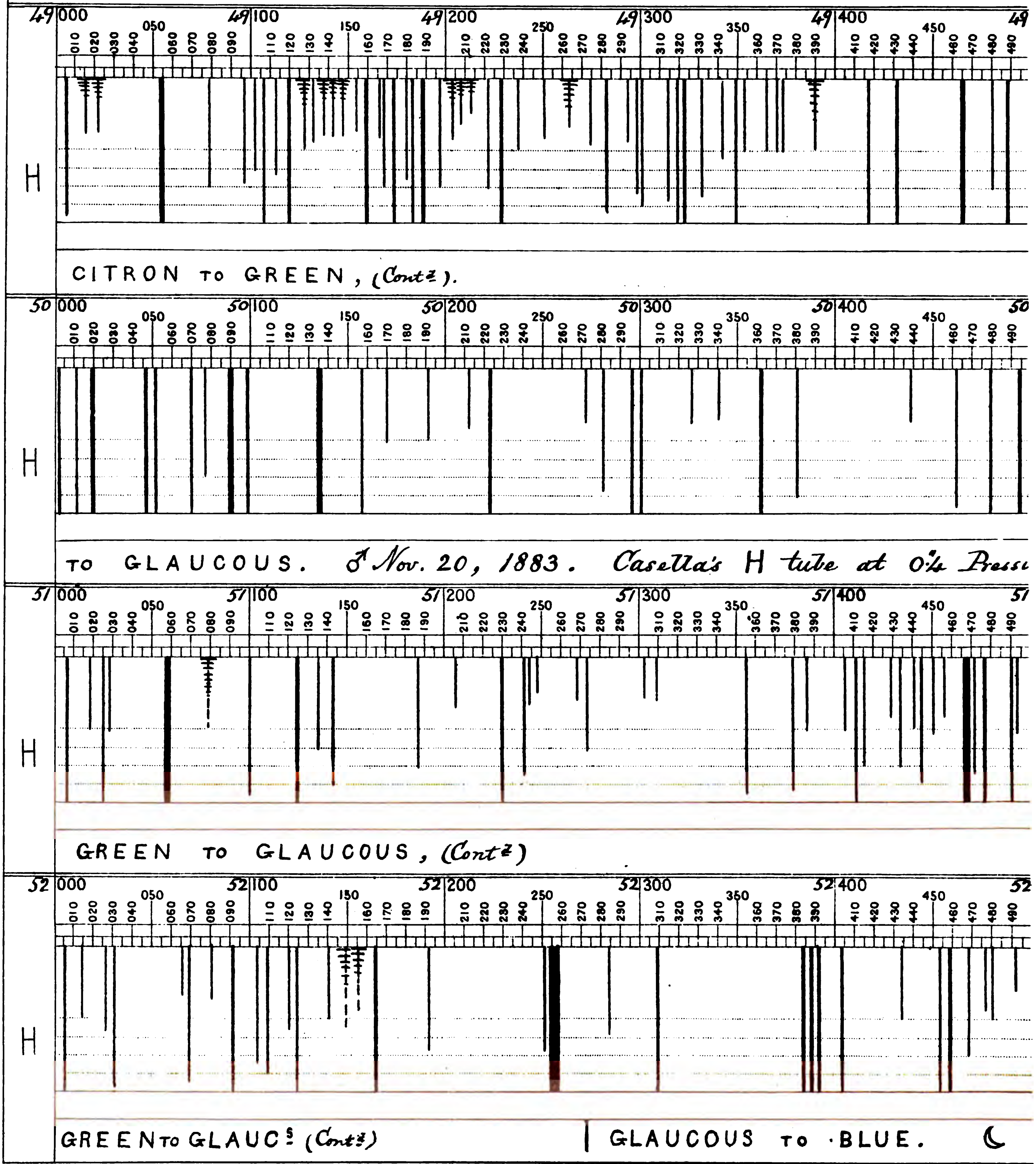


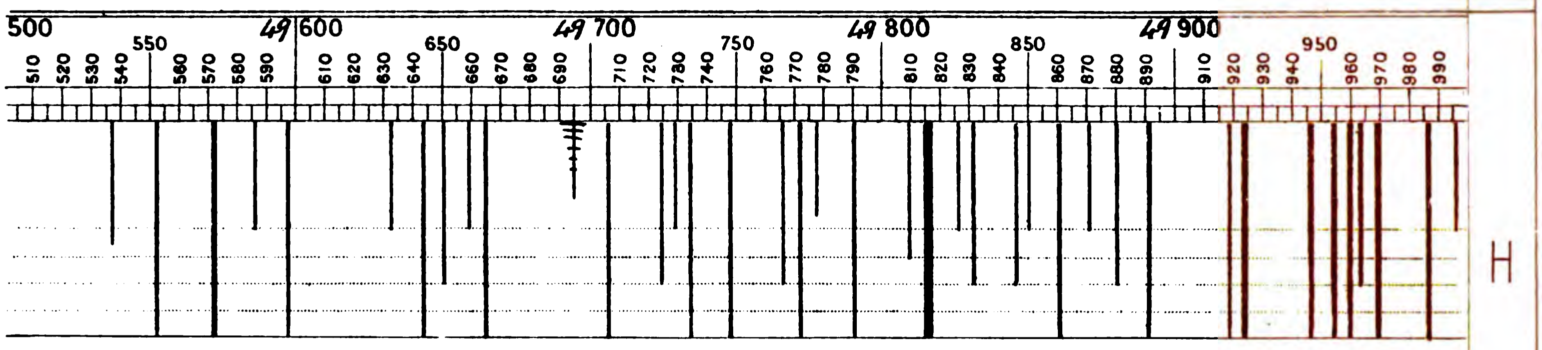

Photo-Lith. 1884.

T. H. del. 2.

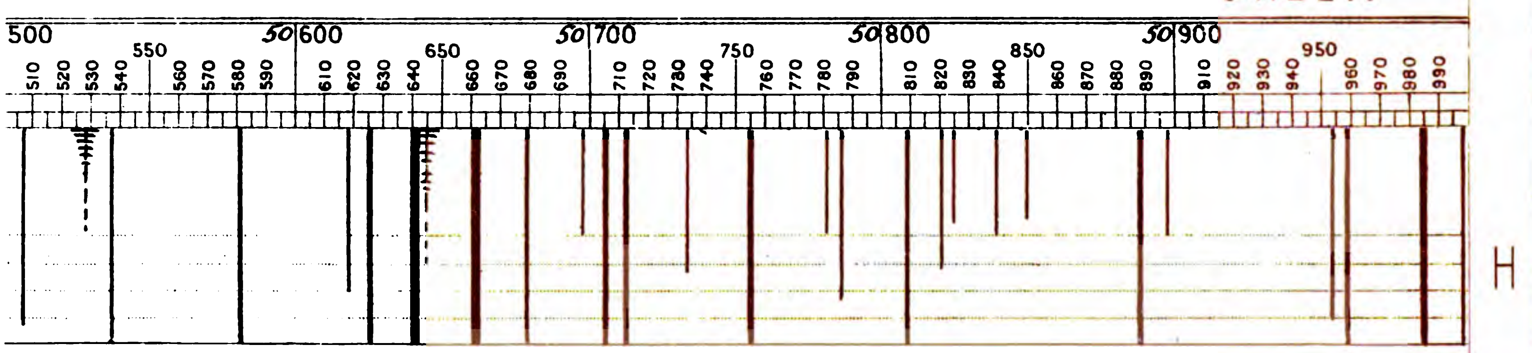
# H IN VAC-


H
CITRON TO GREEN, (Contd).
H
TO GLAUCOUS. ♂ Nov. 20, 1883. Casella's H tube at 0¼ Pressu
H
GREEN TO GLAUCOUS, (Contd)
H
GREEN TO GLAUCS (Contd)
GLAUCOUS TO BLUE.

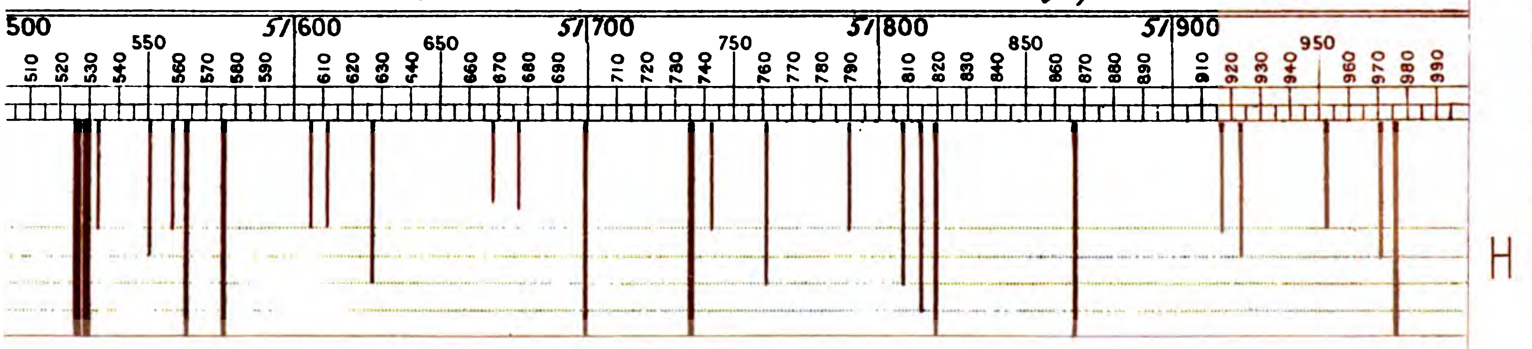
-UUM - TUBE

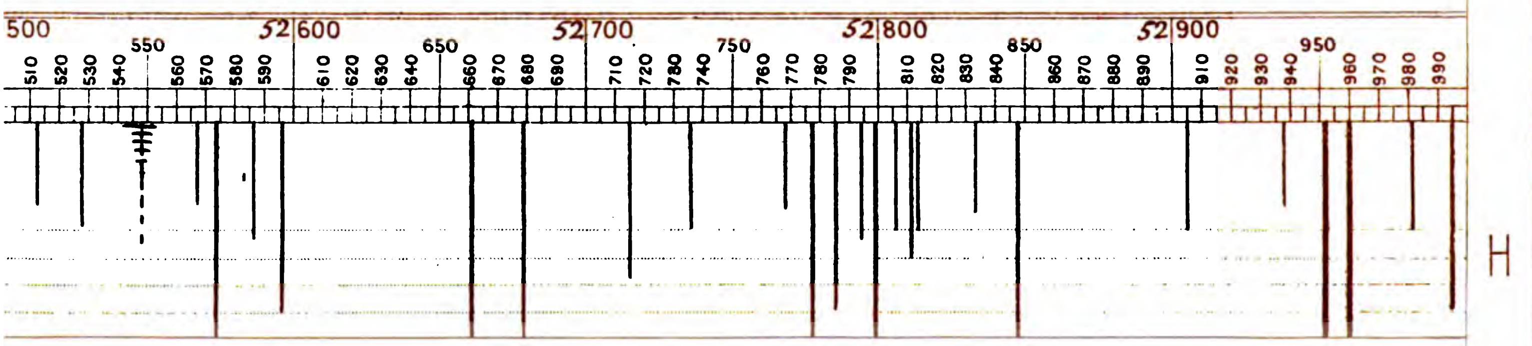


GREEN



re. Prismatic Dispersion = 48° A to H. Mag. power = 21.

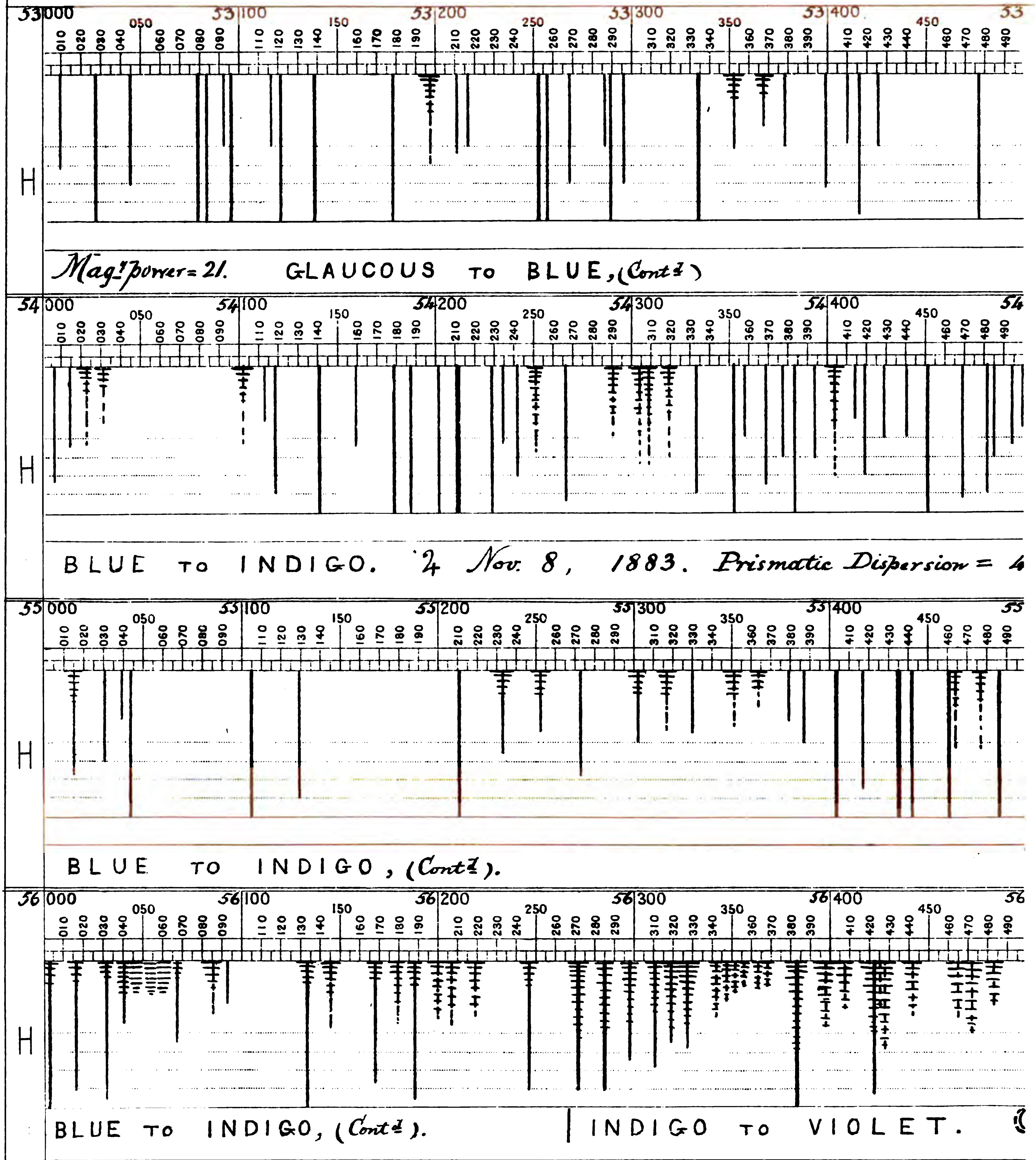




Nov. 5, 1883. Casella's O'4 Pressure tube. Prismatic Dispersion = 48° A to H.

Photo-lith. 1884. T. H. del. 2.

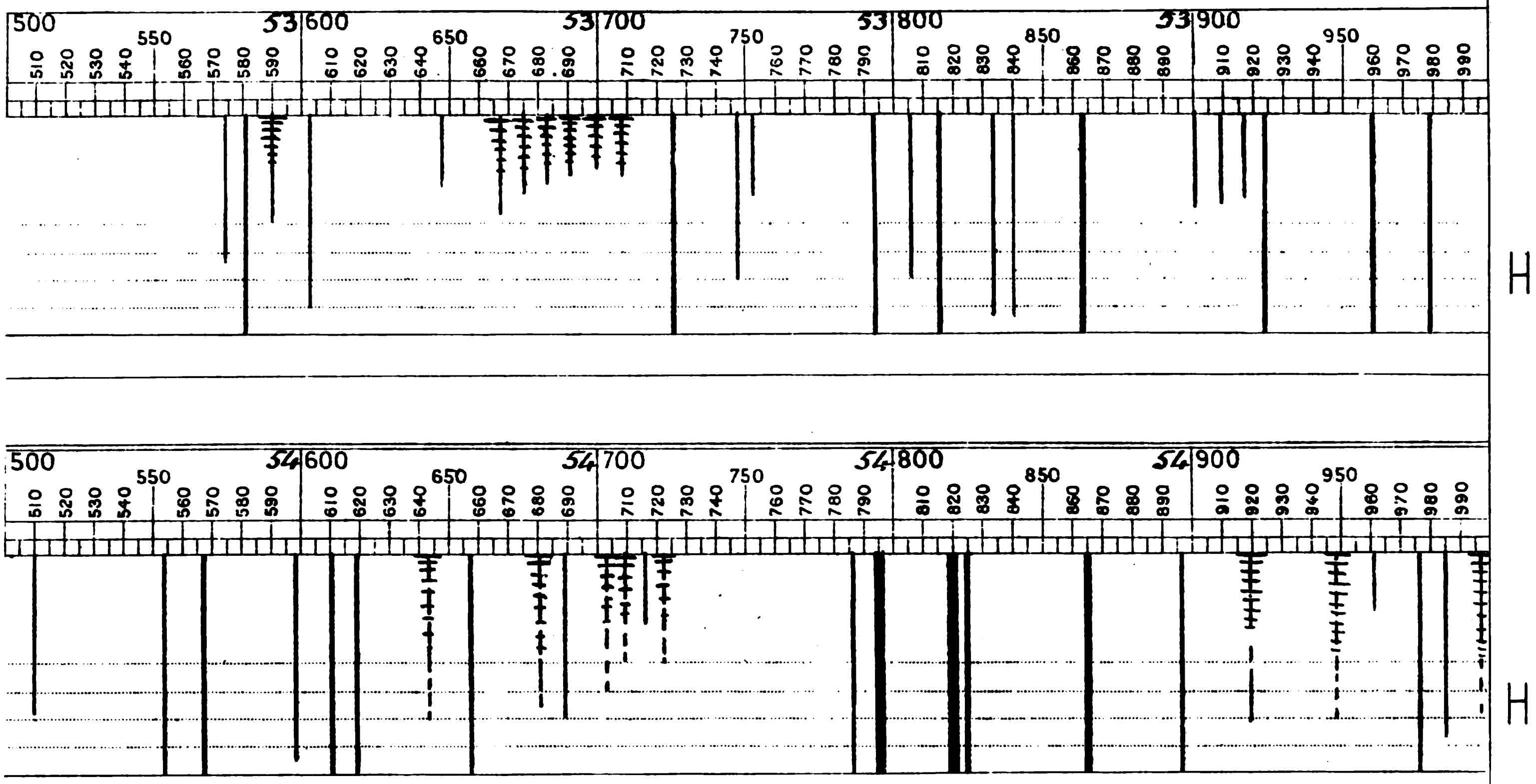
# H IN VAC-



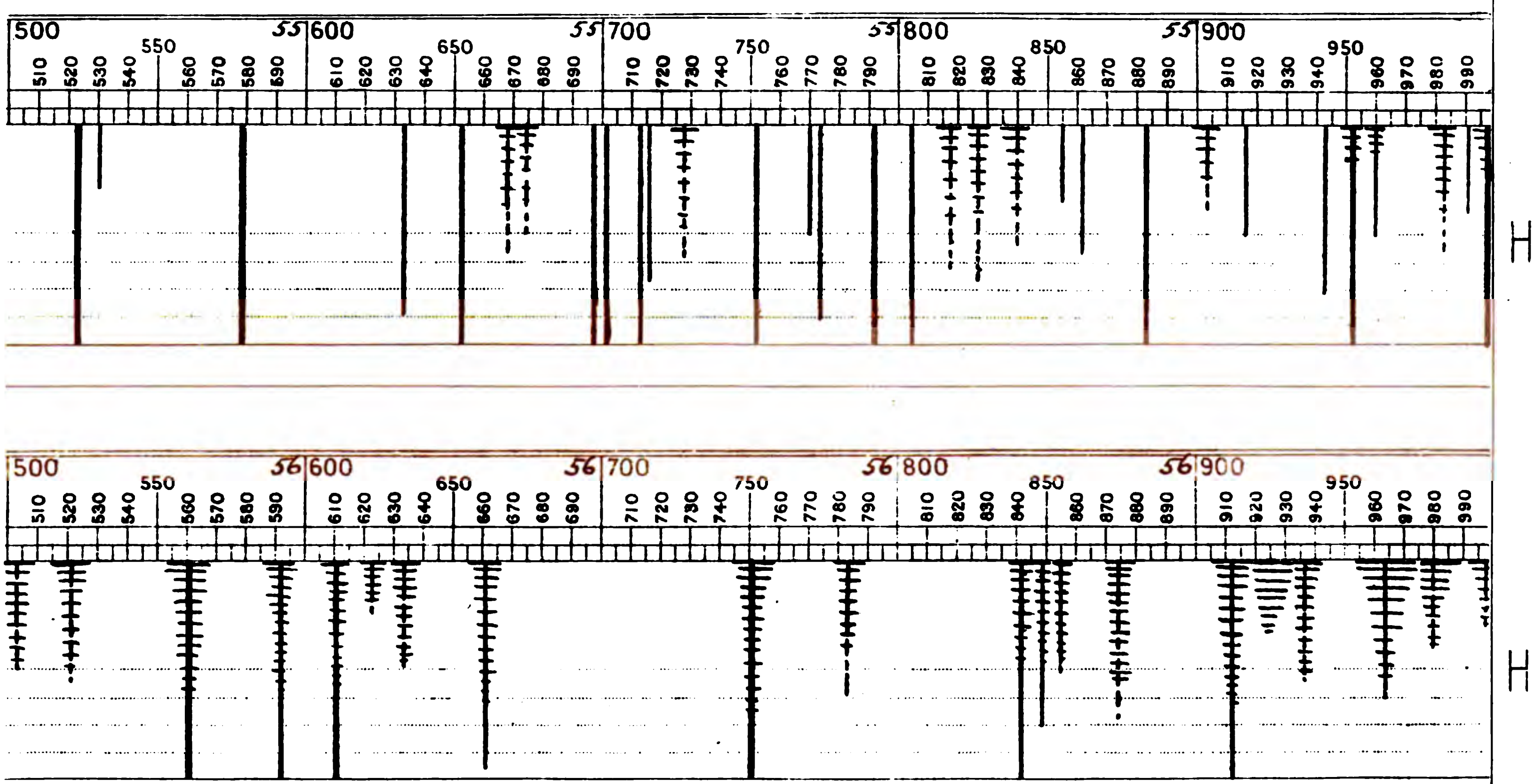

C.P.S. obs. & del. I.

A. Ritchie & Son,

# -UUM-TUBE




*8° A to H. Magnifying power = 21.*



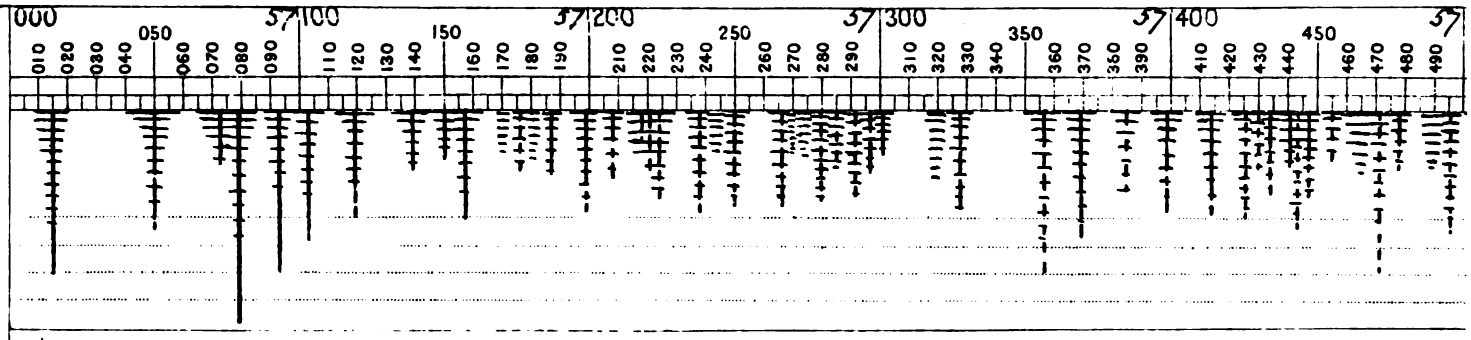

*Nov. 12, 1883. Casella's H-tube at 0''4 Pressure. Dispersion = 48°*

Photo-lith. 1884.

T. H. del. 2

# H IN VAC -

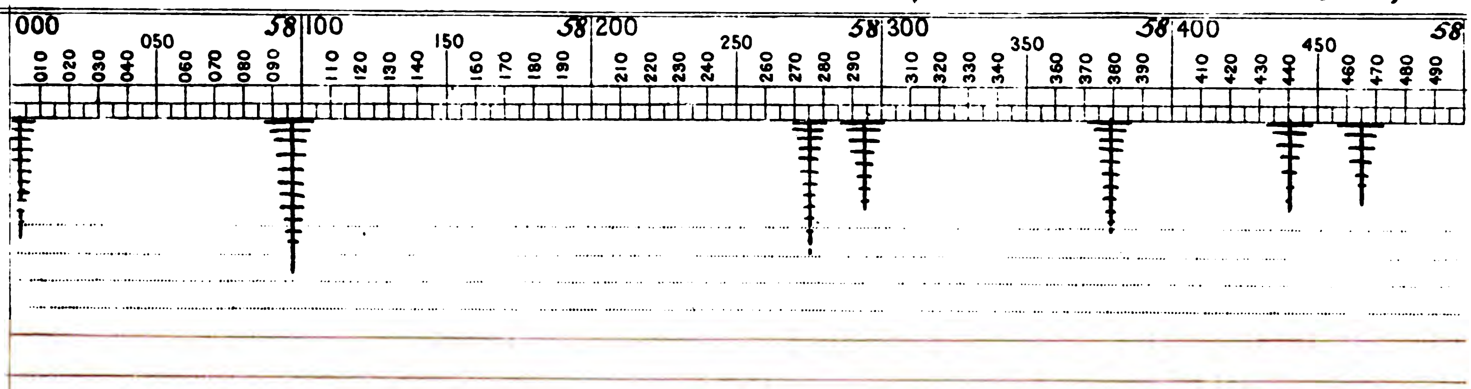
57




H

INDIGO to VIOLET, (Contd) *Magg. power = 21.* *This range pre*

58




H

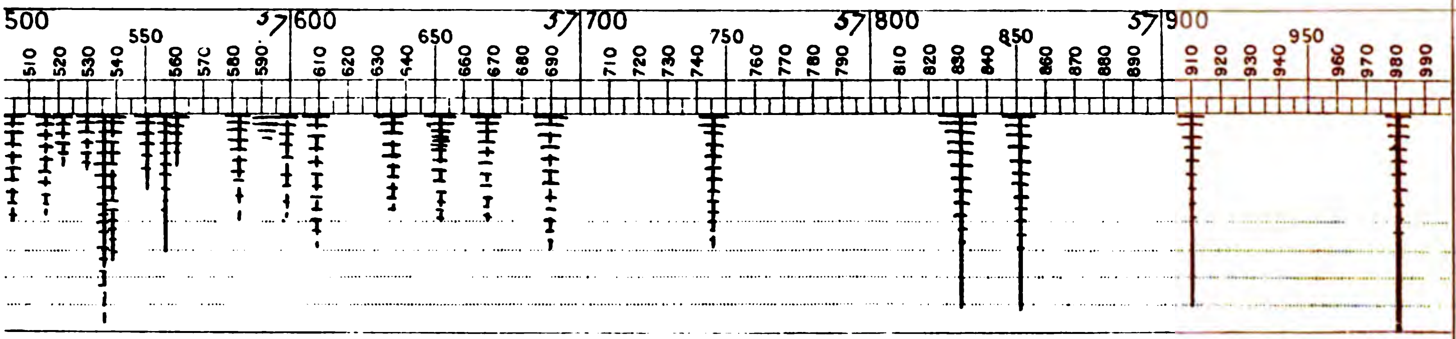
INDIGO. to VIOLET, (Contd).

H

H

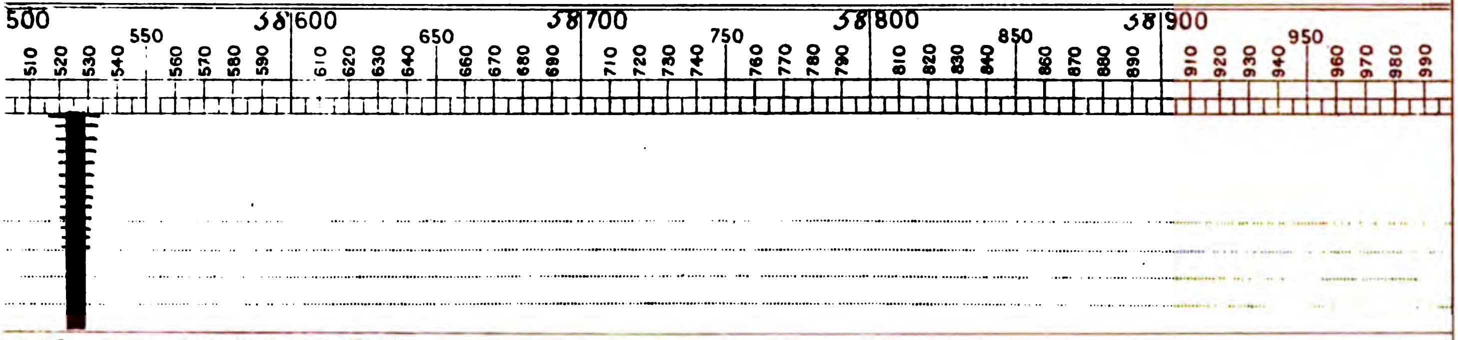
*C.P.S. obs. & del. 1.* *A. Ritchie & Son,*

# -UUM - TUBES



H

iously taken with 36° Dispersion A to H, but with no better definition

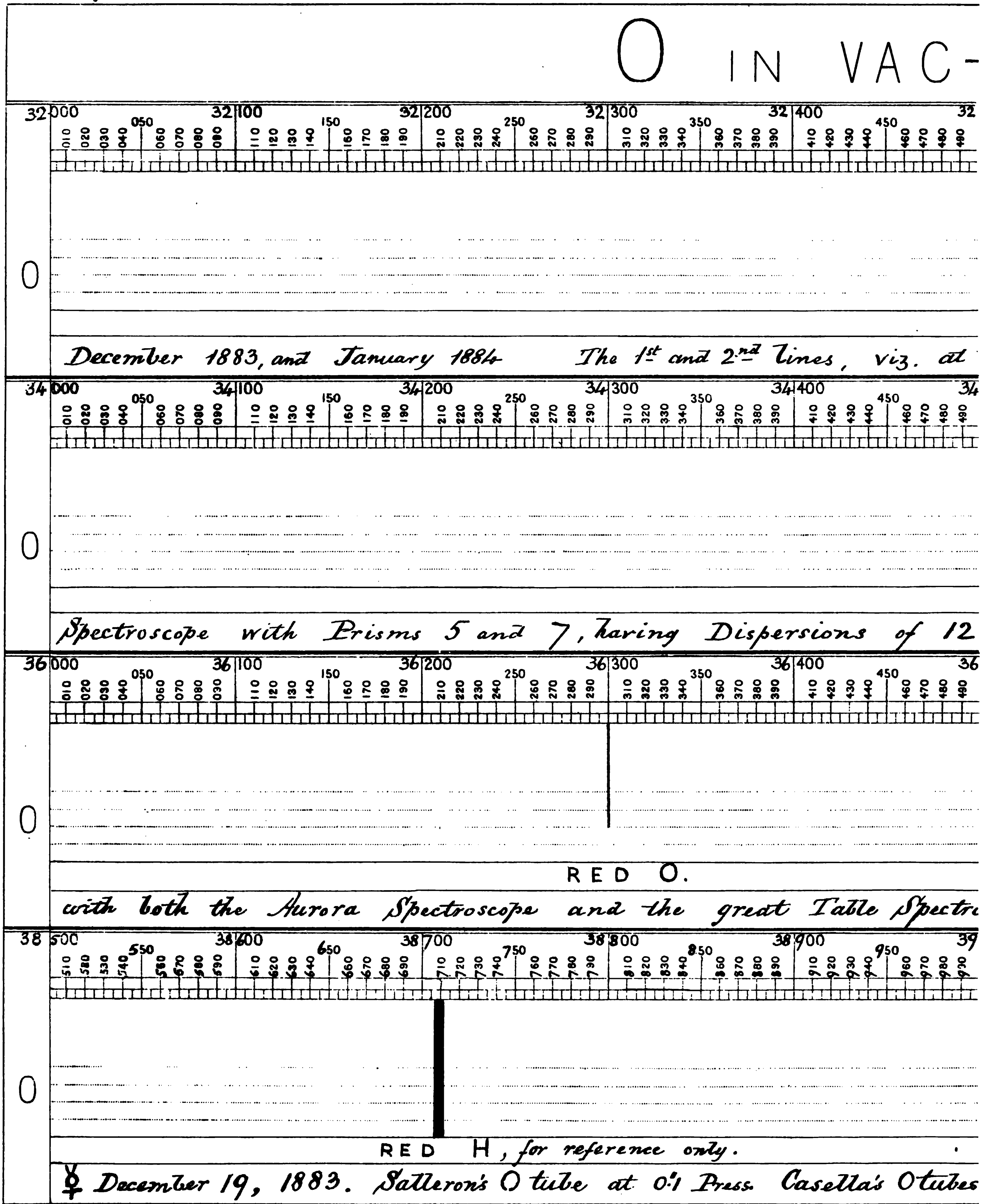


H

VIOLET HYDROGEN.

H

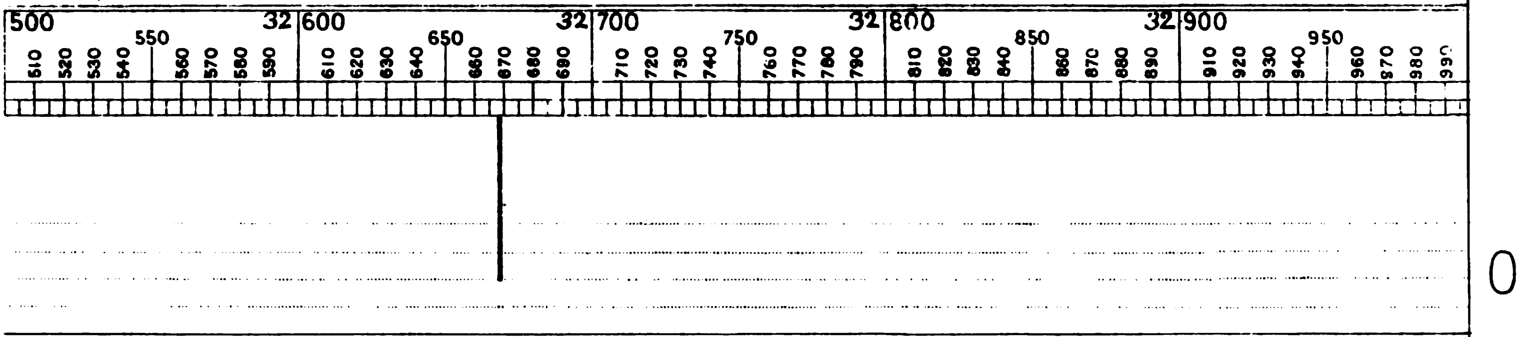
H




C.P.S. obs. & del. 1.

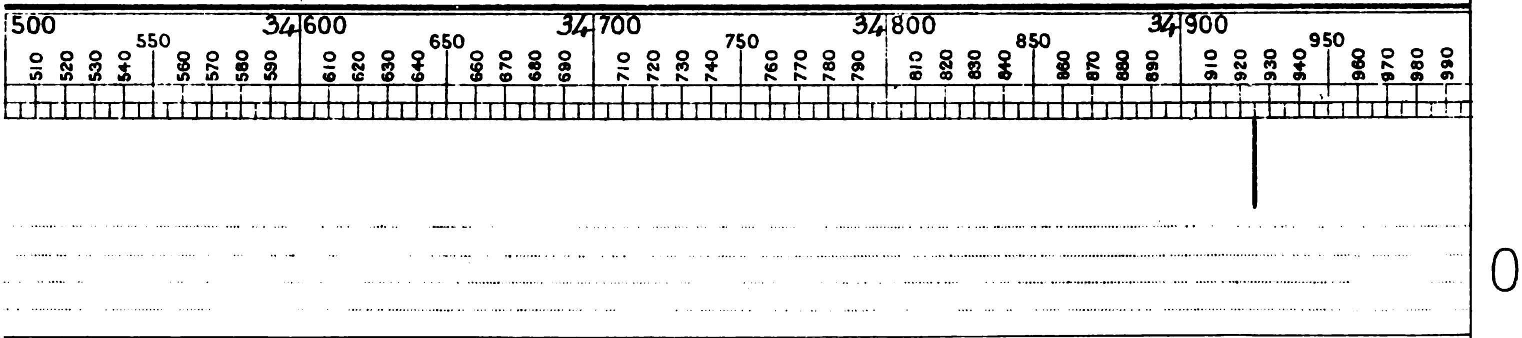
A. Ritchie & Son,

# -UUM - TUBES



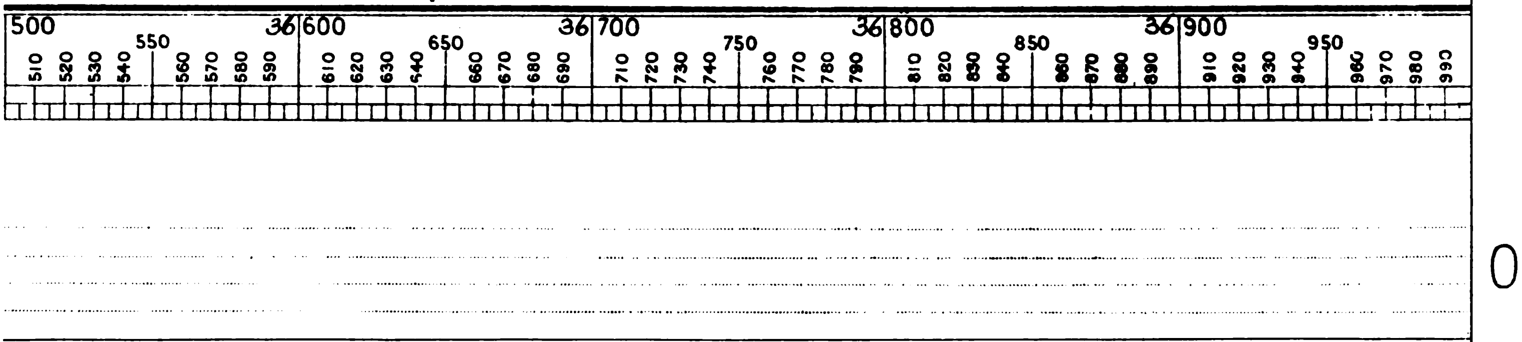

ULTRA RED O

*32 670 and 34 925 W. N. Place, were measured in the Aurora*

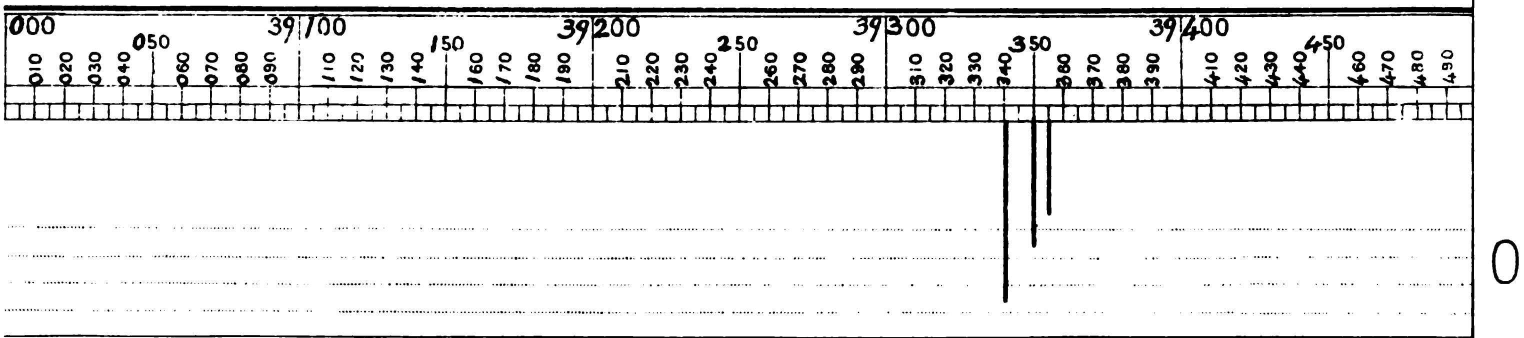



DEEP RED O

*and 24° respectively, A to H : but the third line at 36 300 W.N*



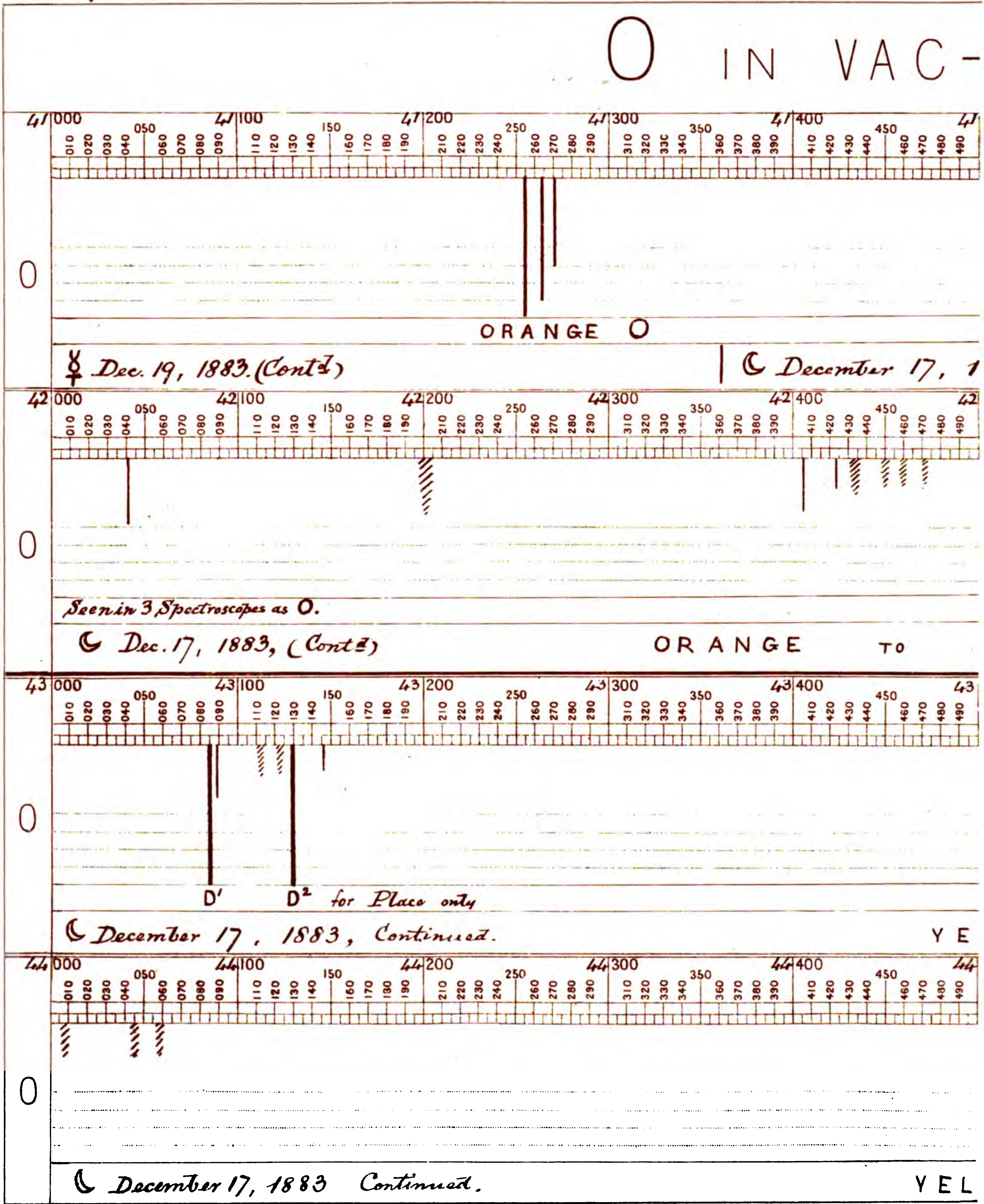

*-scope with Dispersion = 60° A to H.*




SCARLET O.

*at 0.5 and 2.5 Pressure respectively. Prismatic Disp. = 60° A to H, Magn. = 21.*

Photo-lith. 1884. T. H. del. 2.




C. P. S. obs. & del. I.

A. Ritchie & Son.

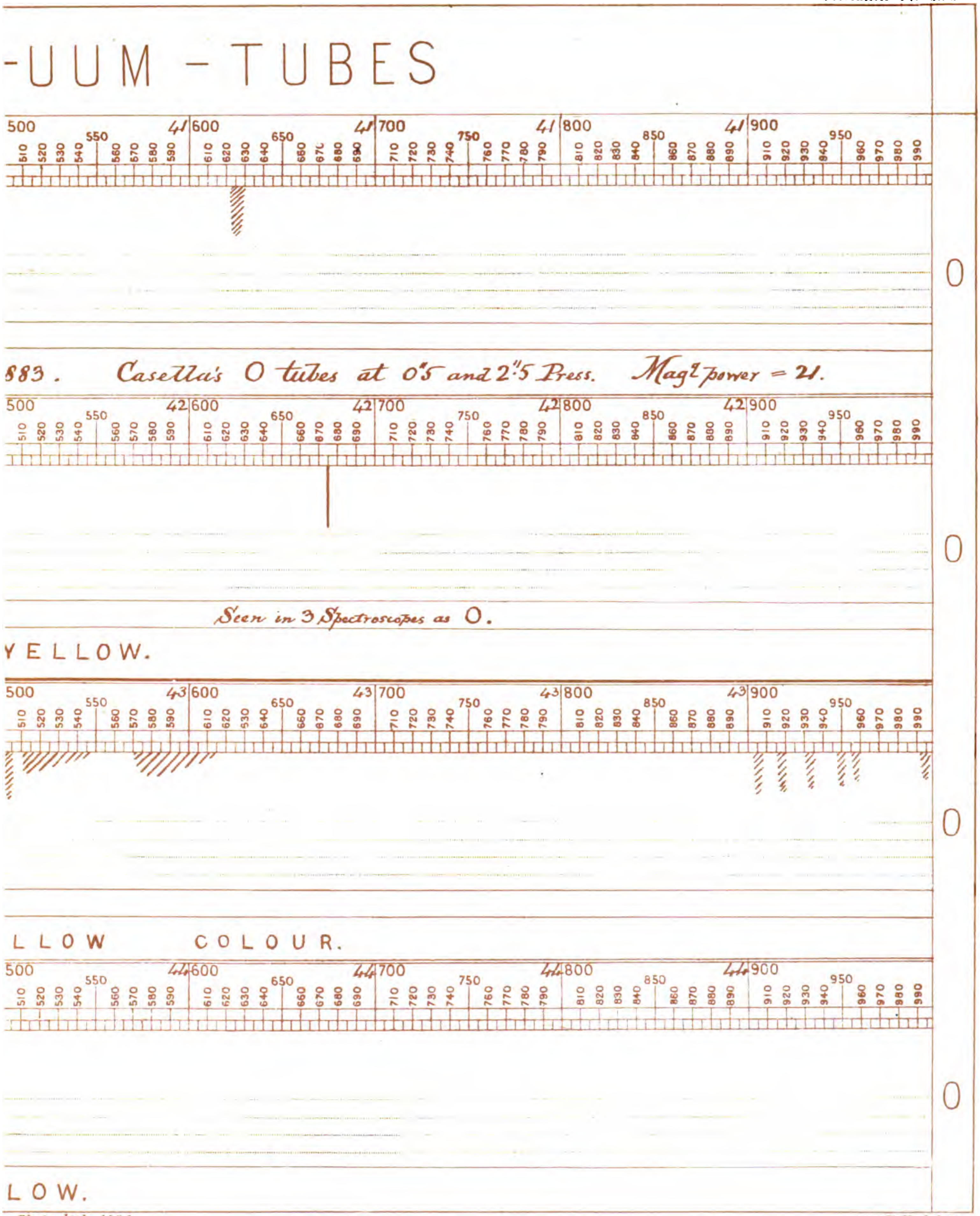
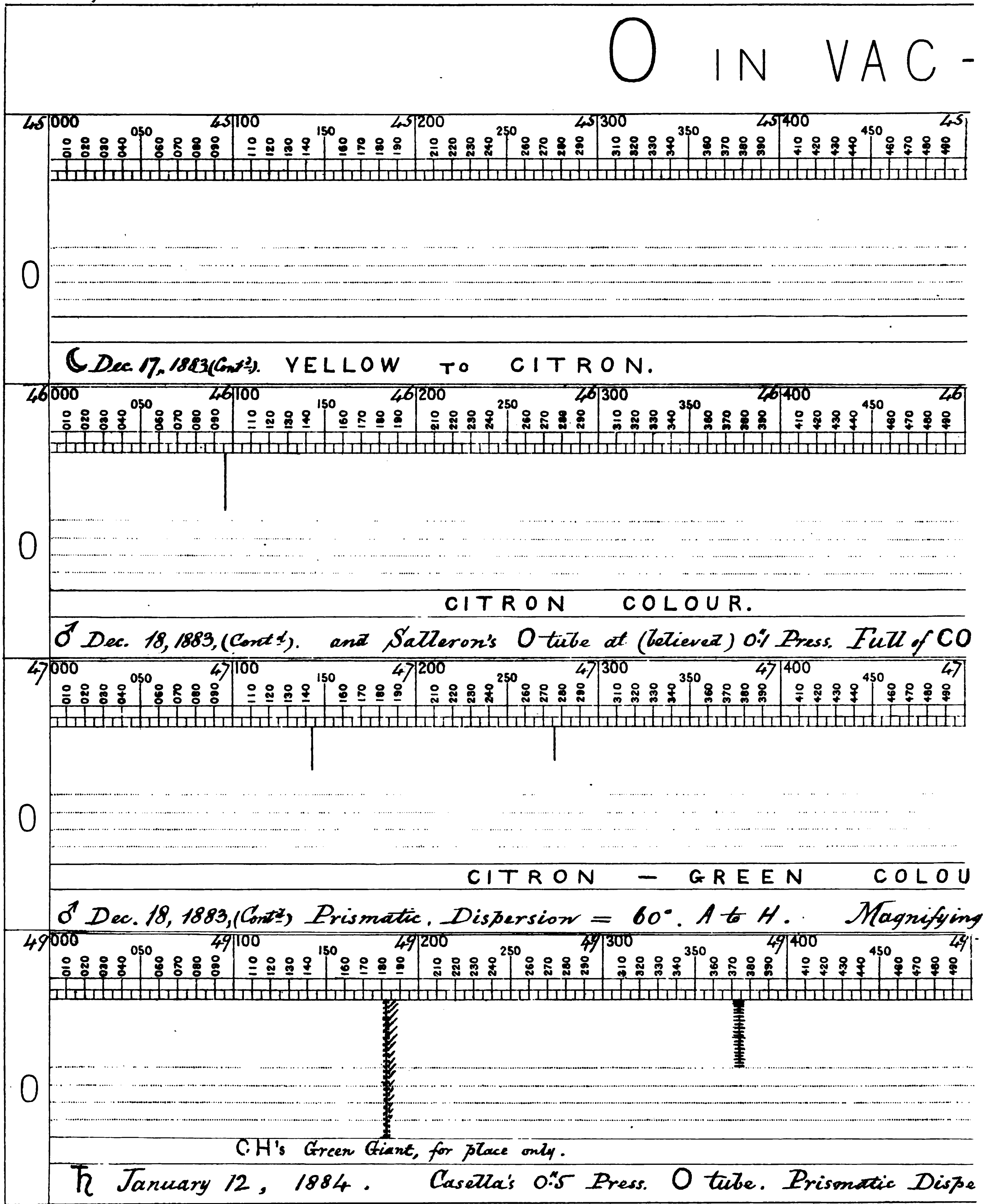



Photo-lith. 1884.

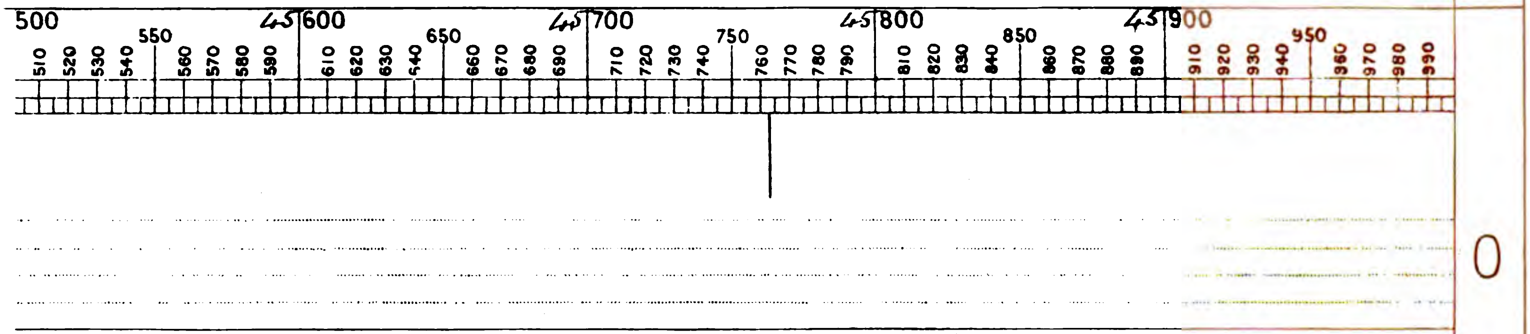
T H. del. 2




C.P.S. obs. & del. 1.

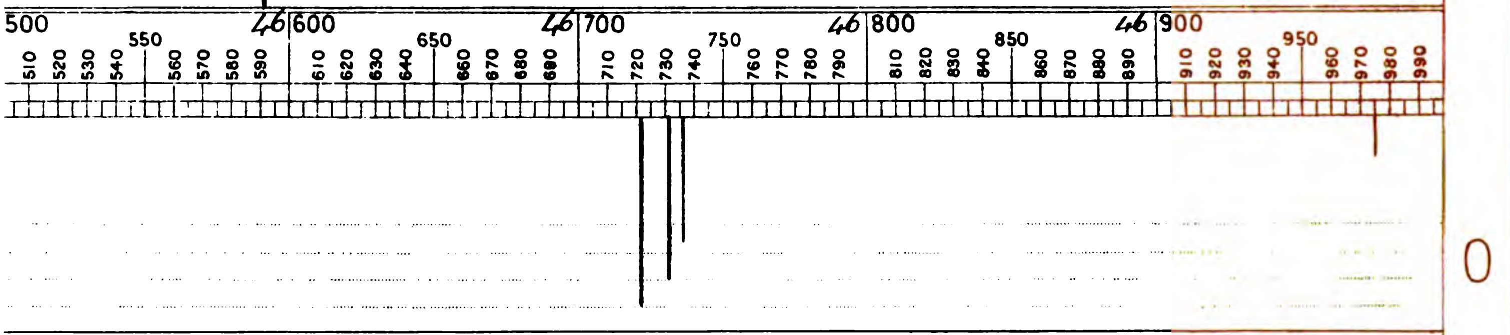
A. Ritchie & Son.

# -UUM - TUBES



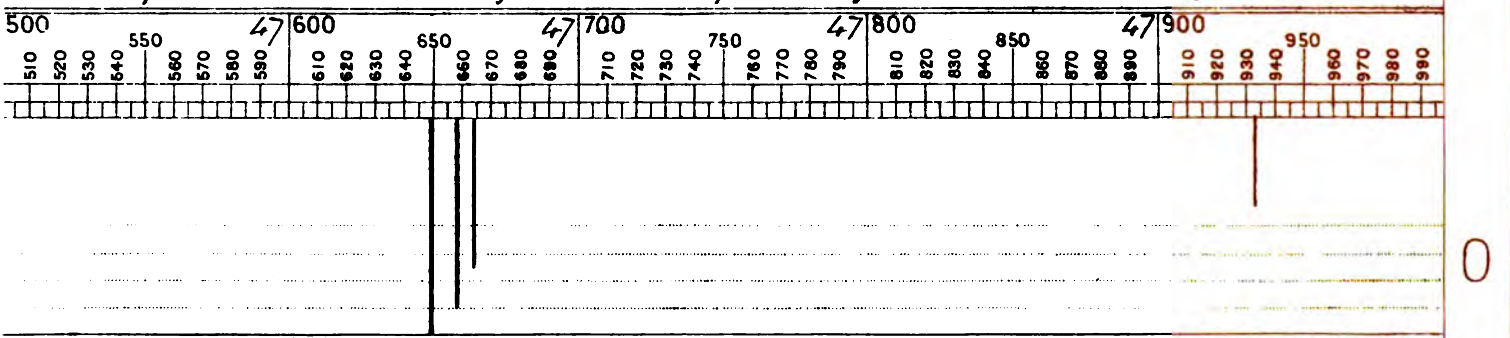
Testified for O by 3 Spectroscopes.

♂ December 18, 1883. Casella's O tubes at 0"5 and 2"5



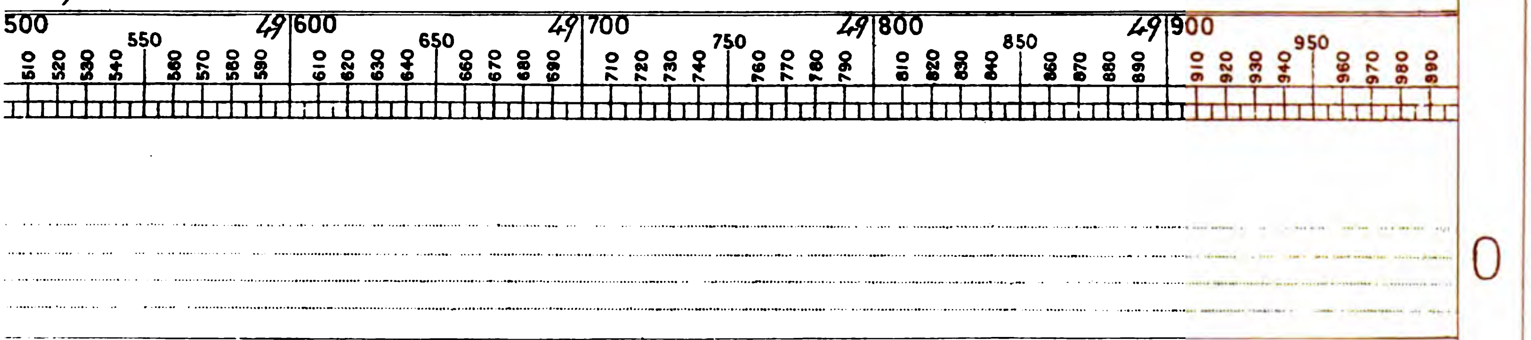
Triply test$^{d}$ for O.

and H impurities, but showing the O triples brighter than Casella's purer tubes.



R. Triply test$^{d}$ for O.

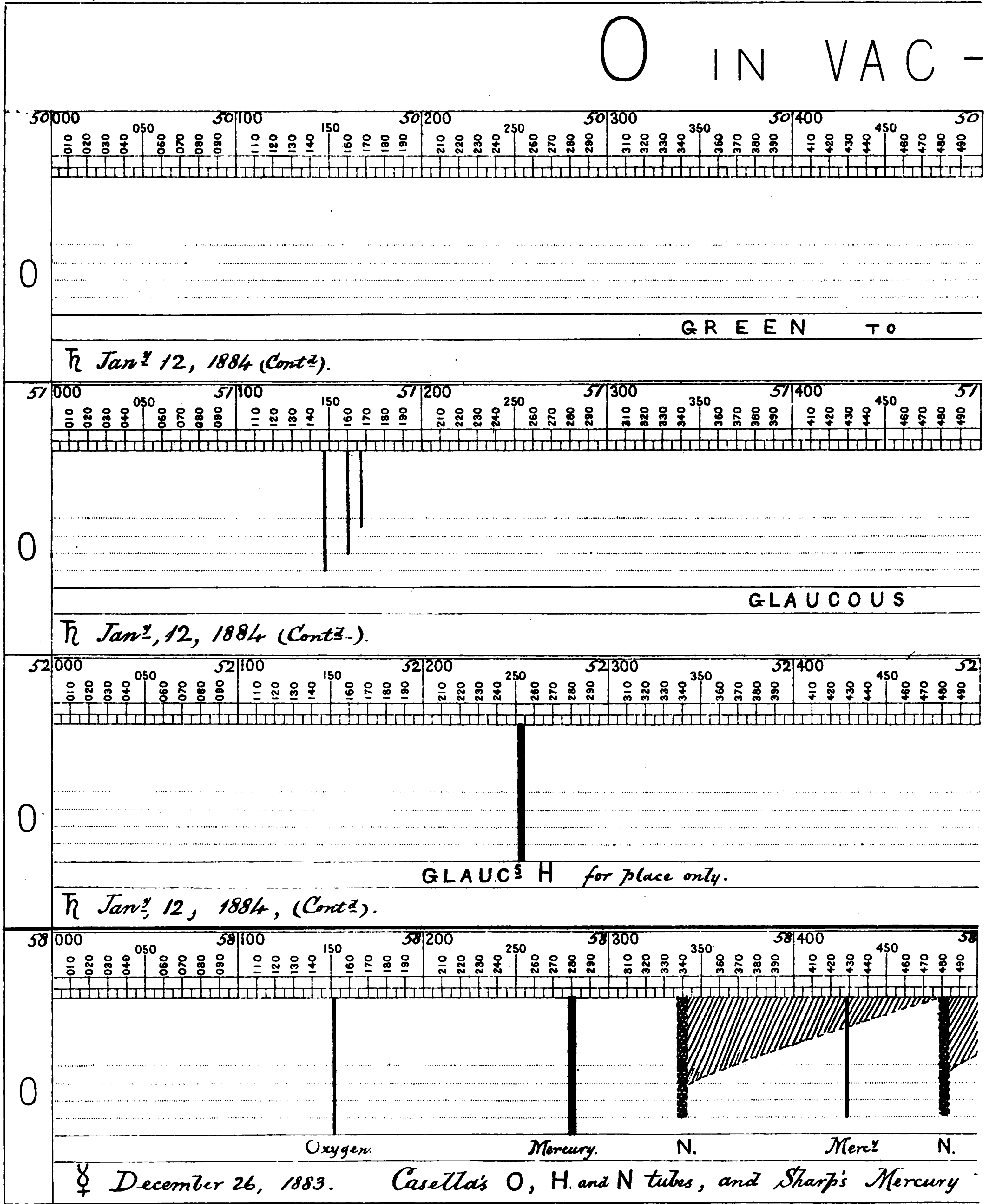
power = 21.



GREEN COLOUR.

rsion = 48°. Magnifying power = 21.

Photo-Lith. 1884. T. H. del. 2.




C.P.S. obs. & del. I.

A. Ritchie & Son,

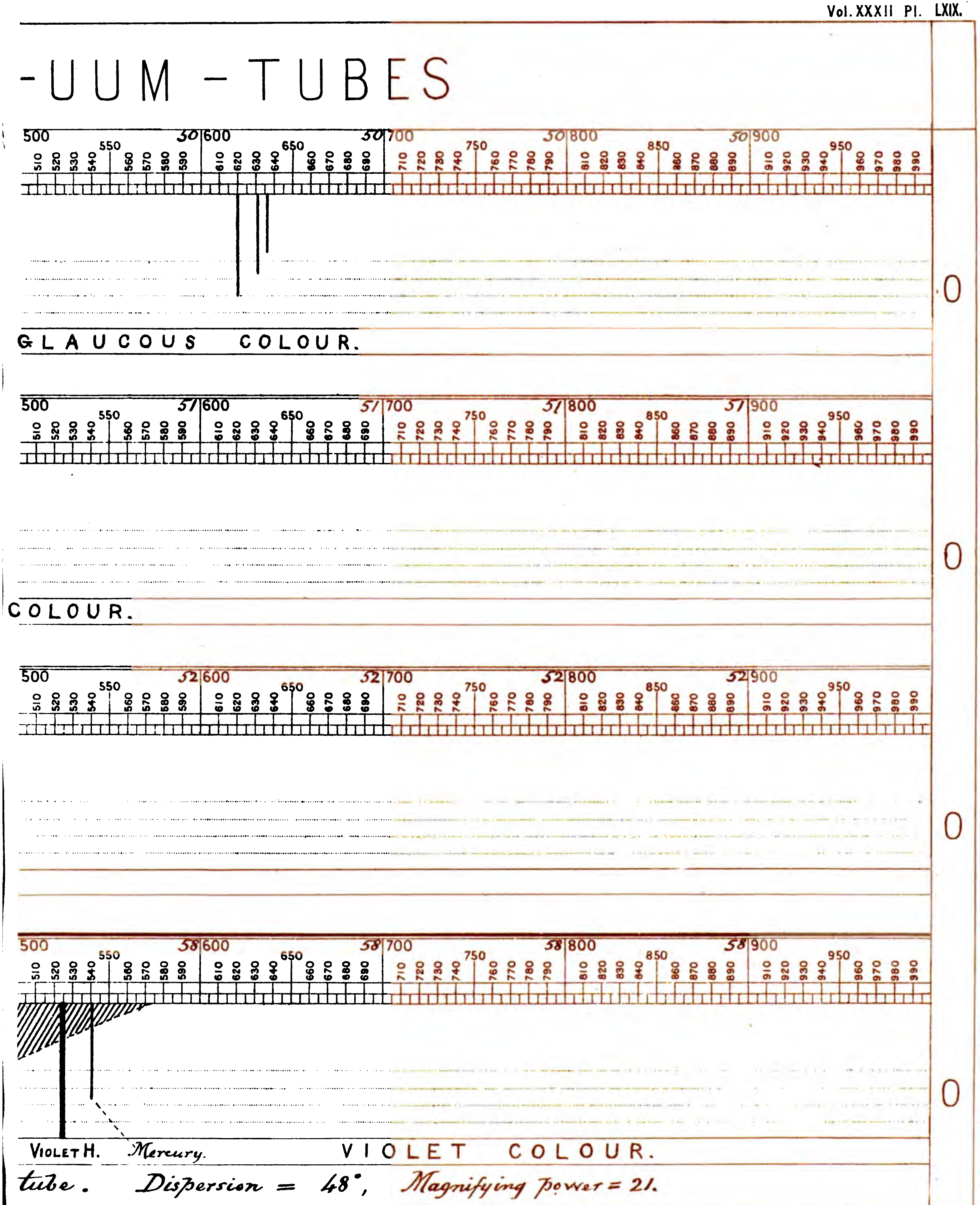
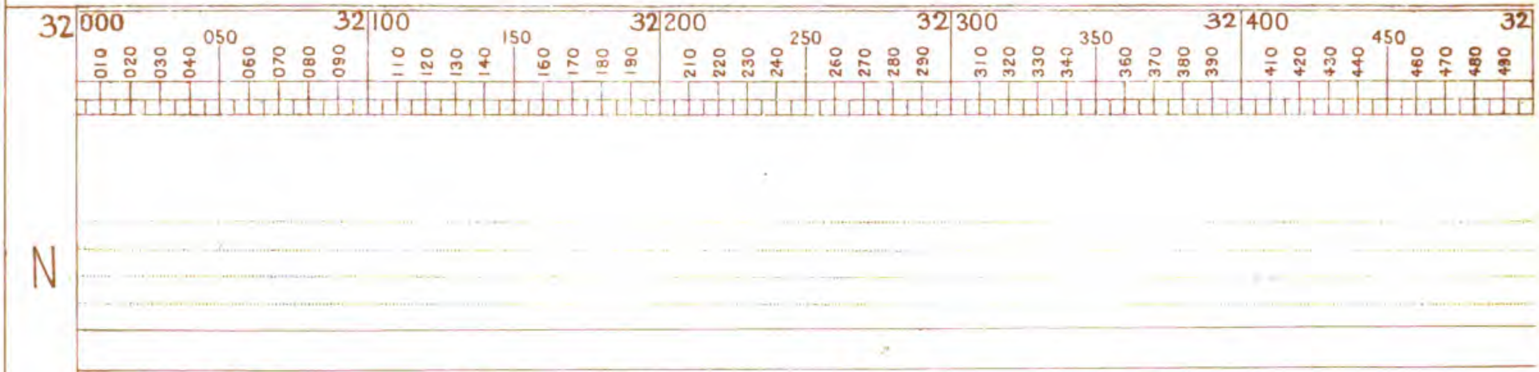
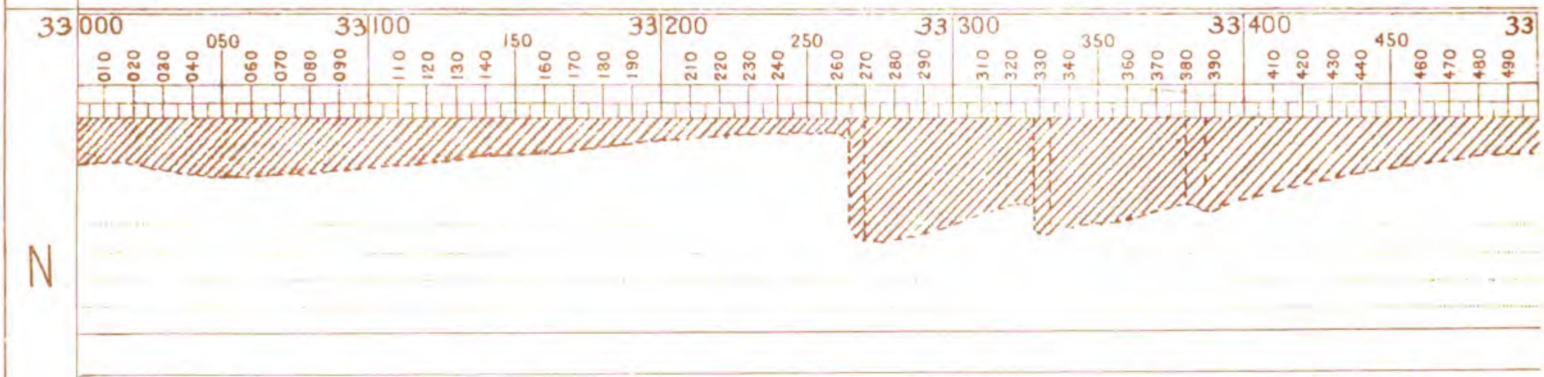



Photo-Lith. 1884. T H. del 2.

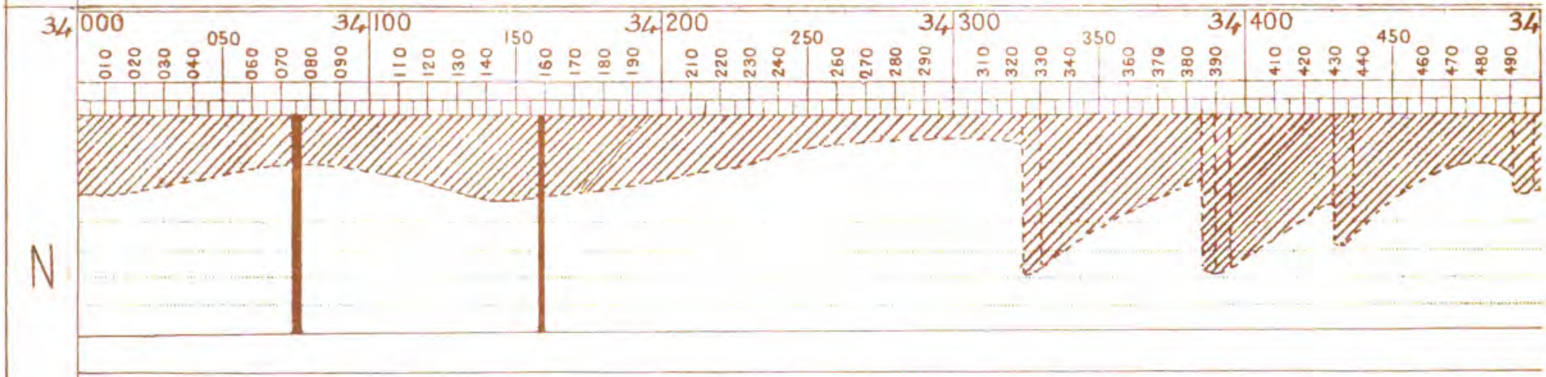
# N IN VAC-



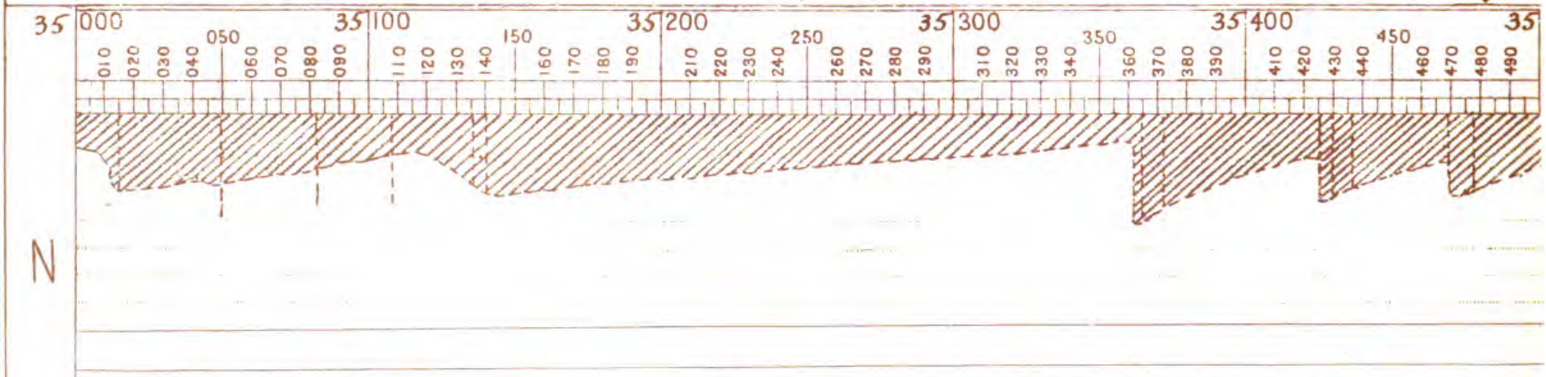

♄ 5th January, 1884. Casella's N tube at 0·1" Pressure, as seen




ULTRA-RED, (Contd.) *Dispersion = 24° A to H, Mag.s pow*

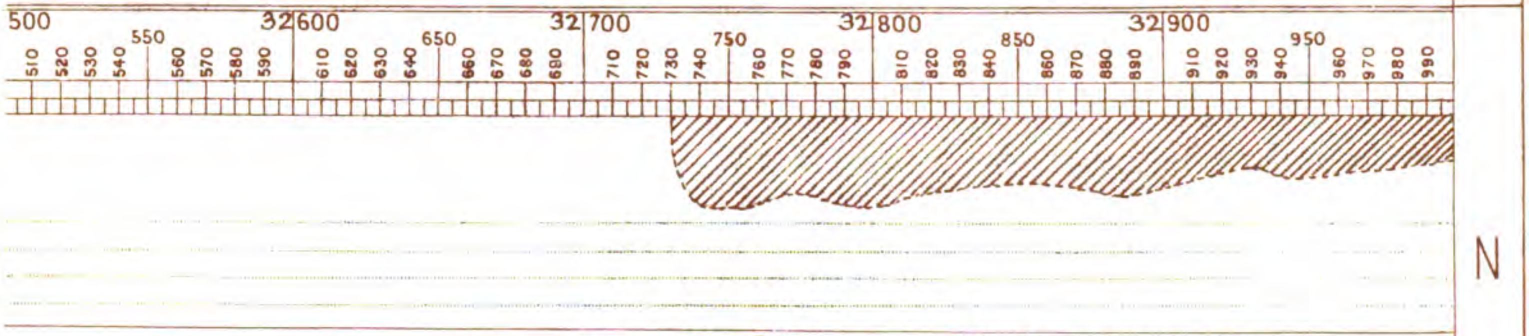



ULTRA-RED, (Contd.). *This triple of lines ( A.S. Herschel's triple )*



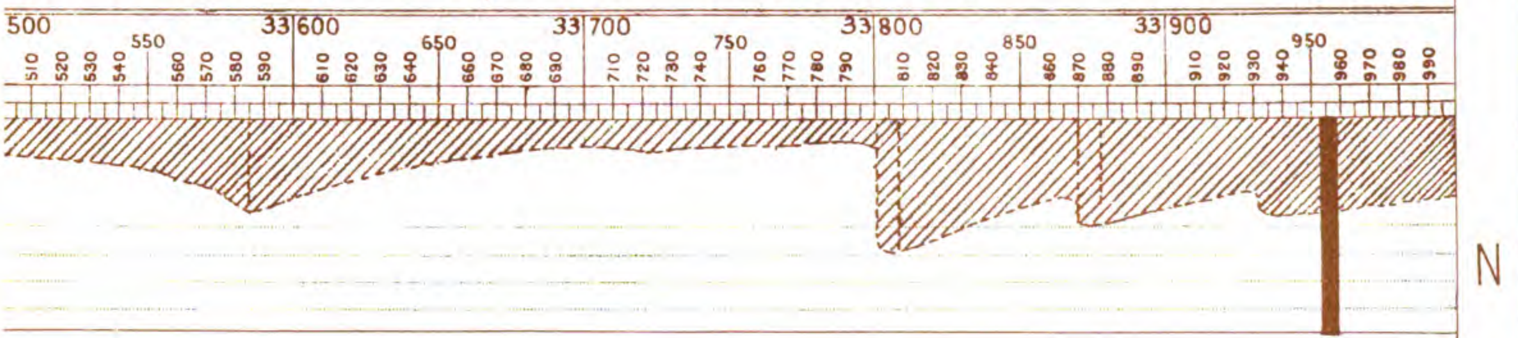

ULTRA-RED, (Contd.) *This ultra-Red Group of N bands.*

# -UUM - TUBES

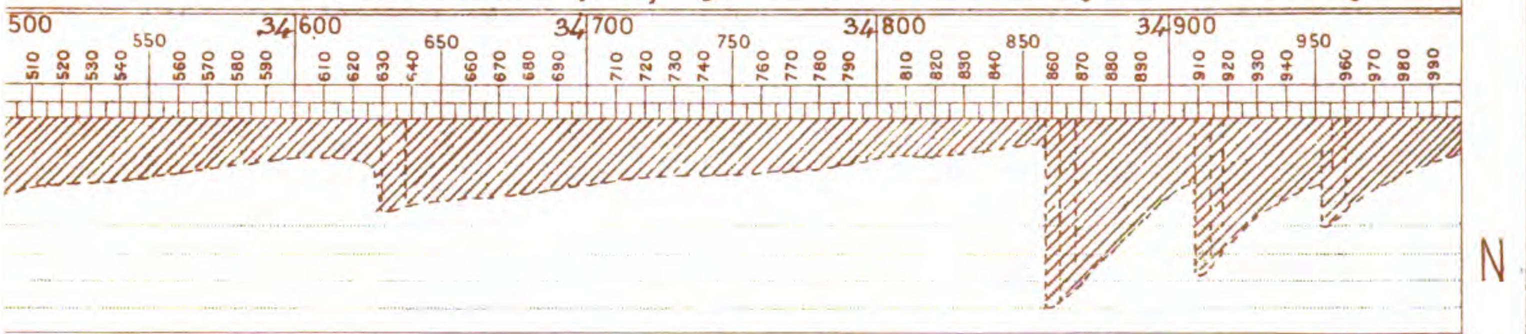



*Earliest N band or light perceivable.*

*in Aurora Spectroscope.* ULTRA-RED.

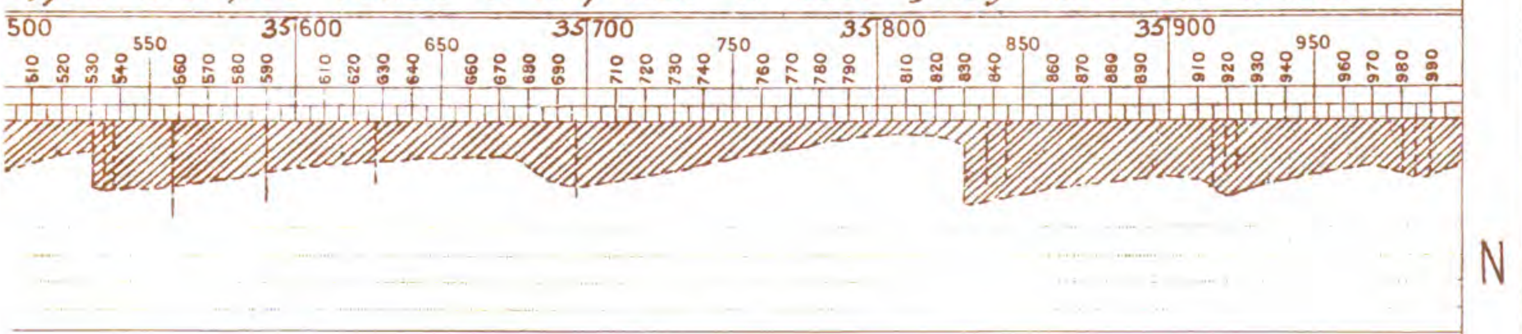



*er = 14. This ultra-Red group of bands increasing in intensity.*




*Max. Intensity for Ultra-Red Group of bands.*

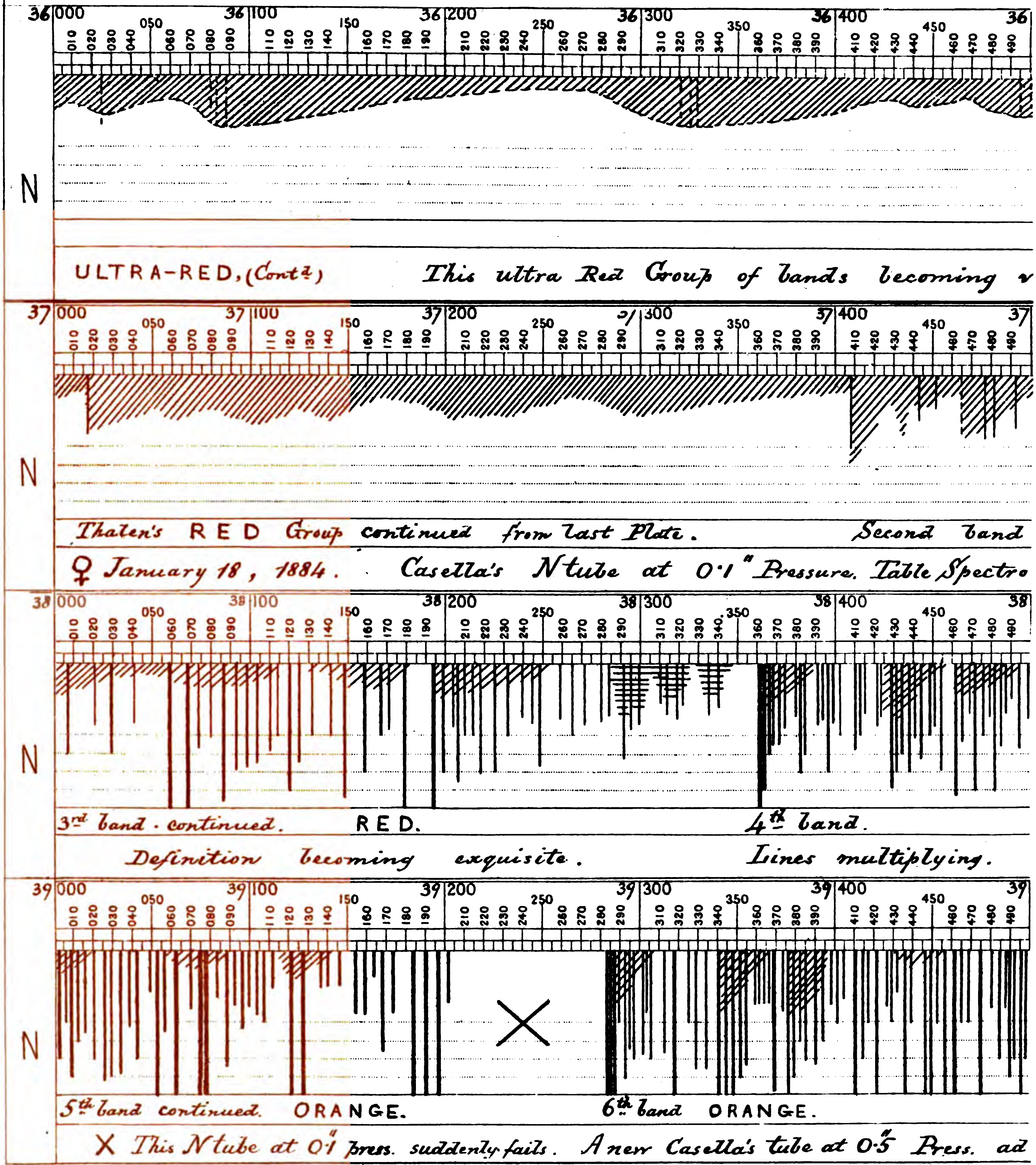
*33,955 to 34,158 W.N.Pl. is only seen in tubes of very small Pressure.*




*beginning to pale again.*

Photo-lith. 1884. T.H. del. 2.

# N IN VAC-




C. P. S. obs. & del. 1.

A. Ritchie & Son,

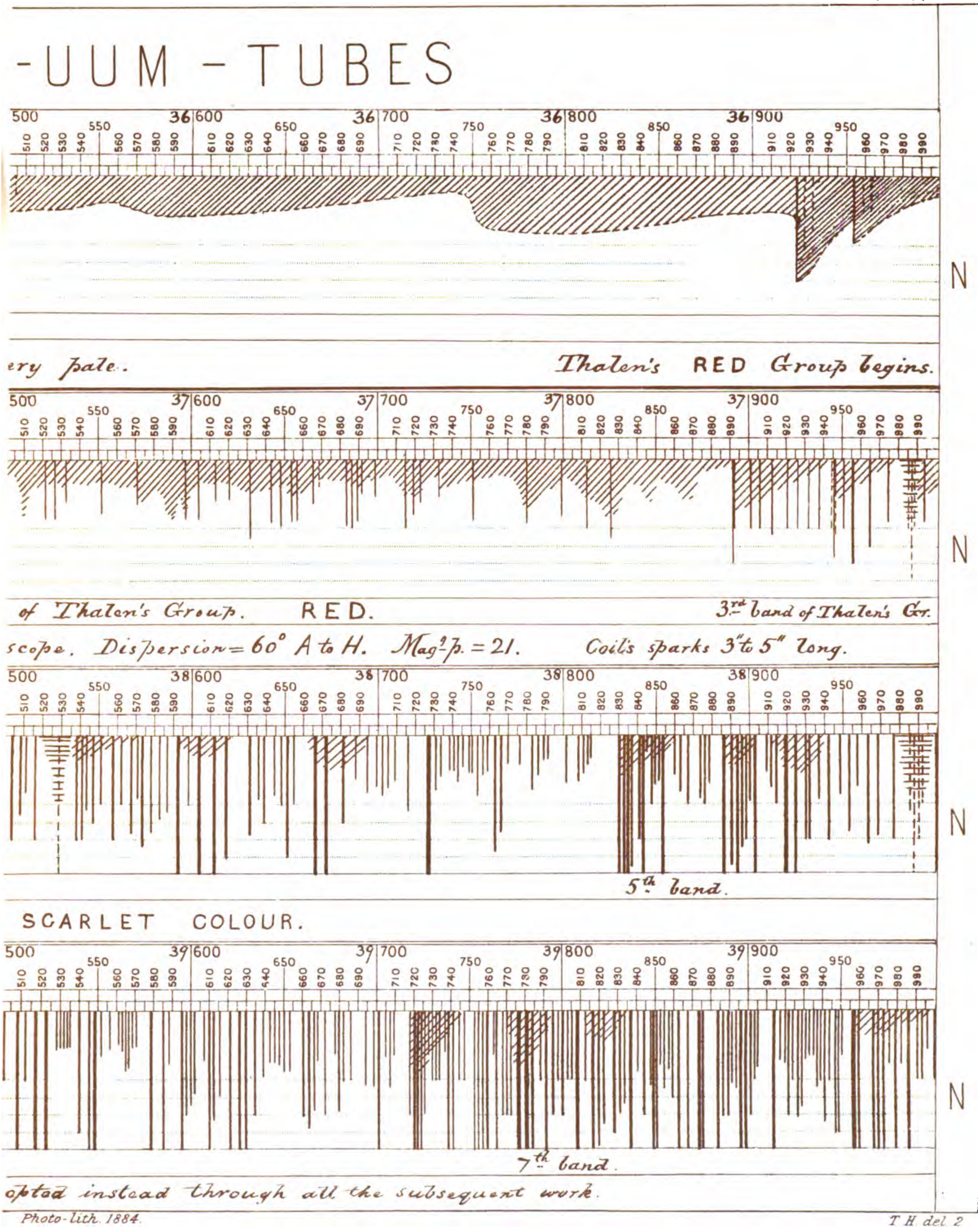
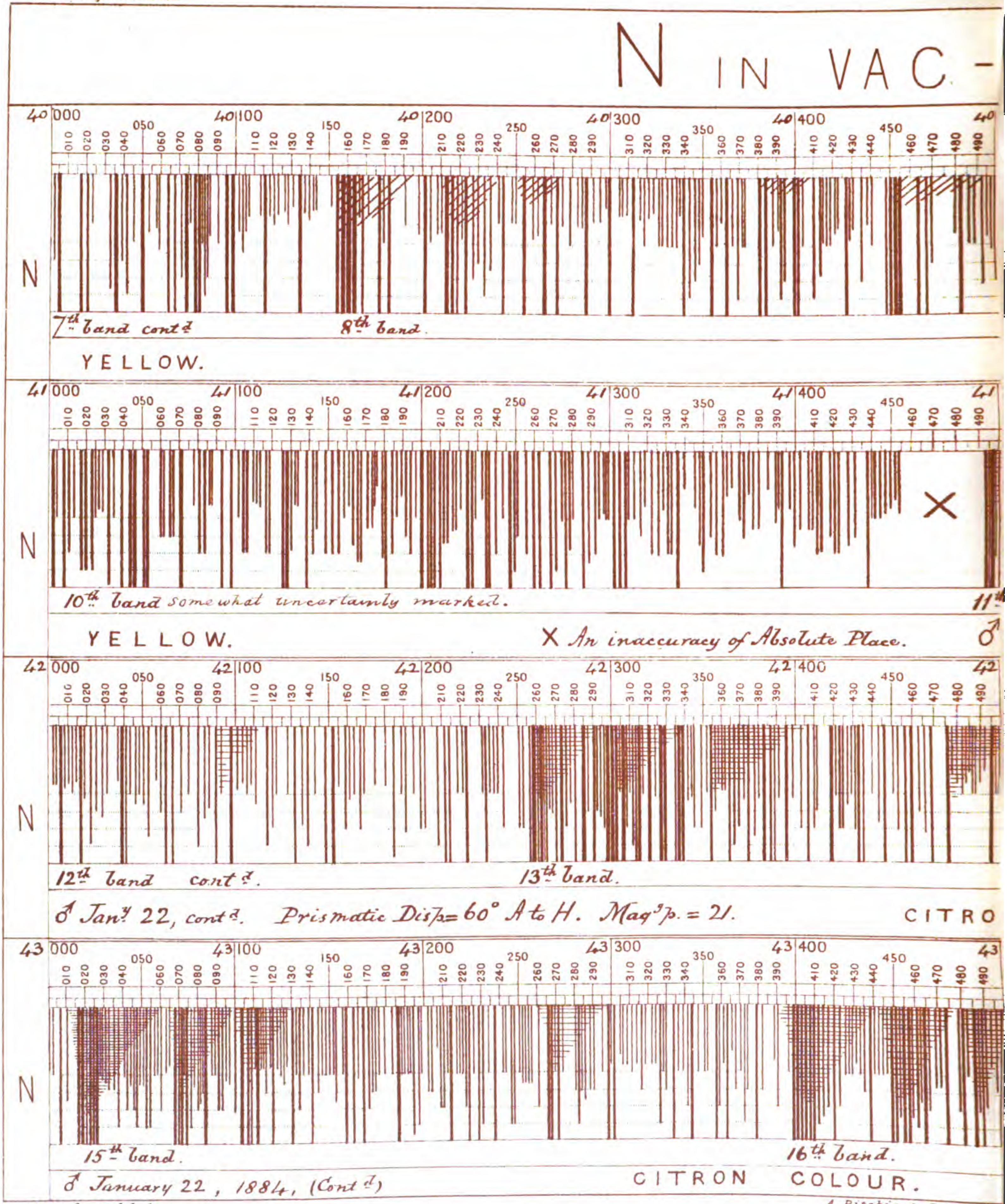


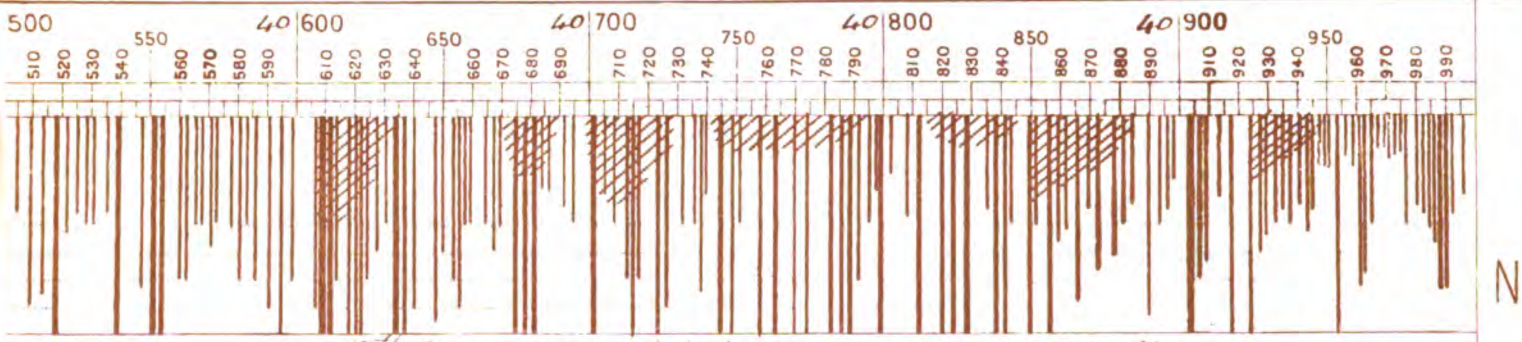

Photo-lith. 1884.

T H del 2

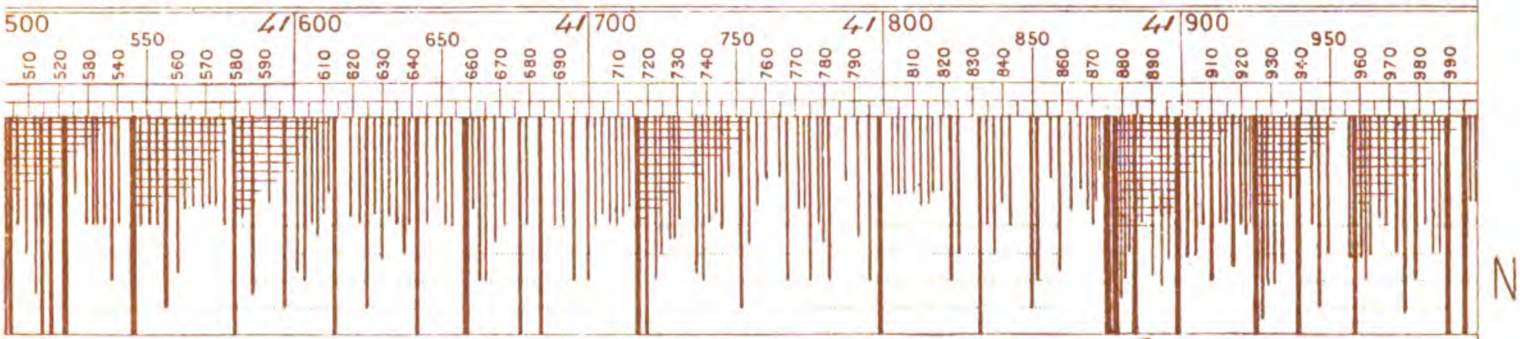



C.P.S. obs. & del. 1. A. Ritchie & Son.

# -UUM - TUBES

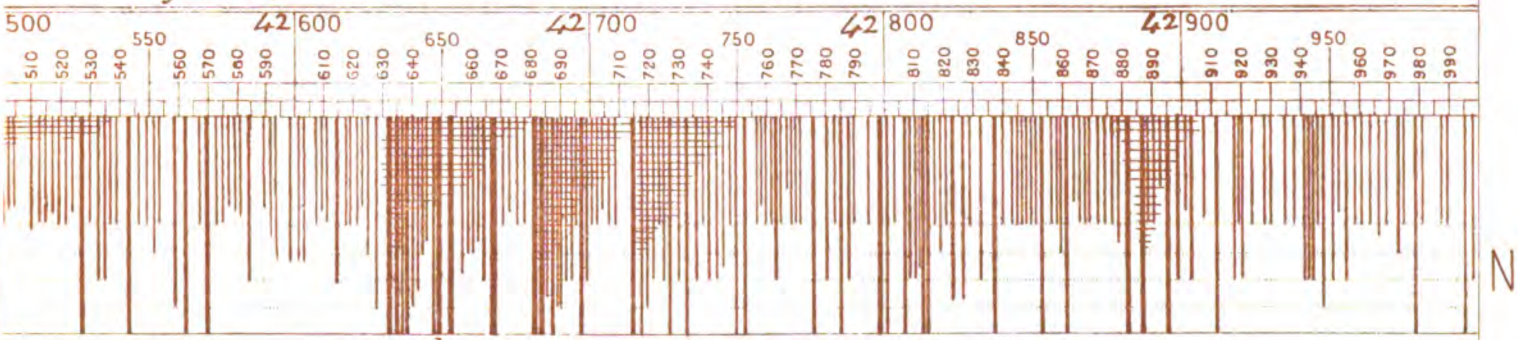



*9th band rather fainter and more scantily lined.*



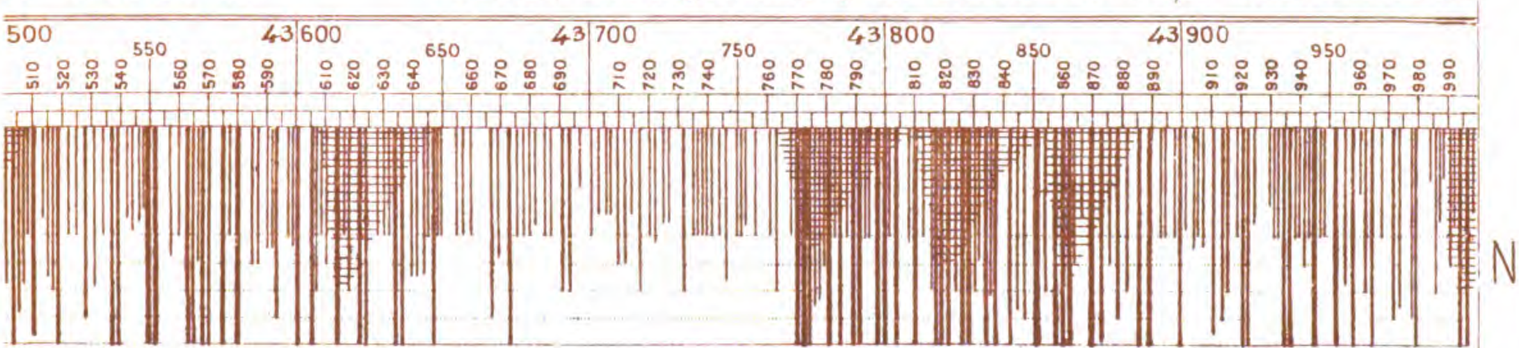

*band begins more strongly defined again.* *12th band.*

*January 22, 1884. Casella's 0·5 Press. N tube.*



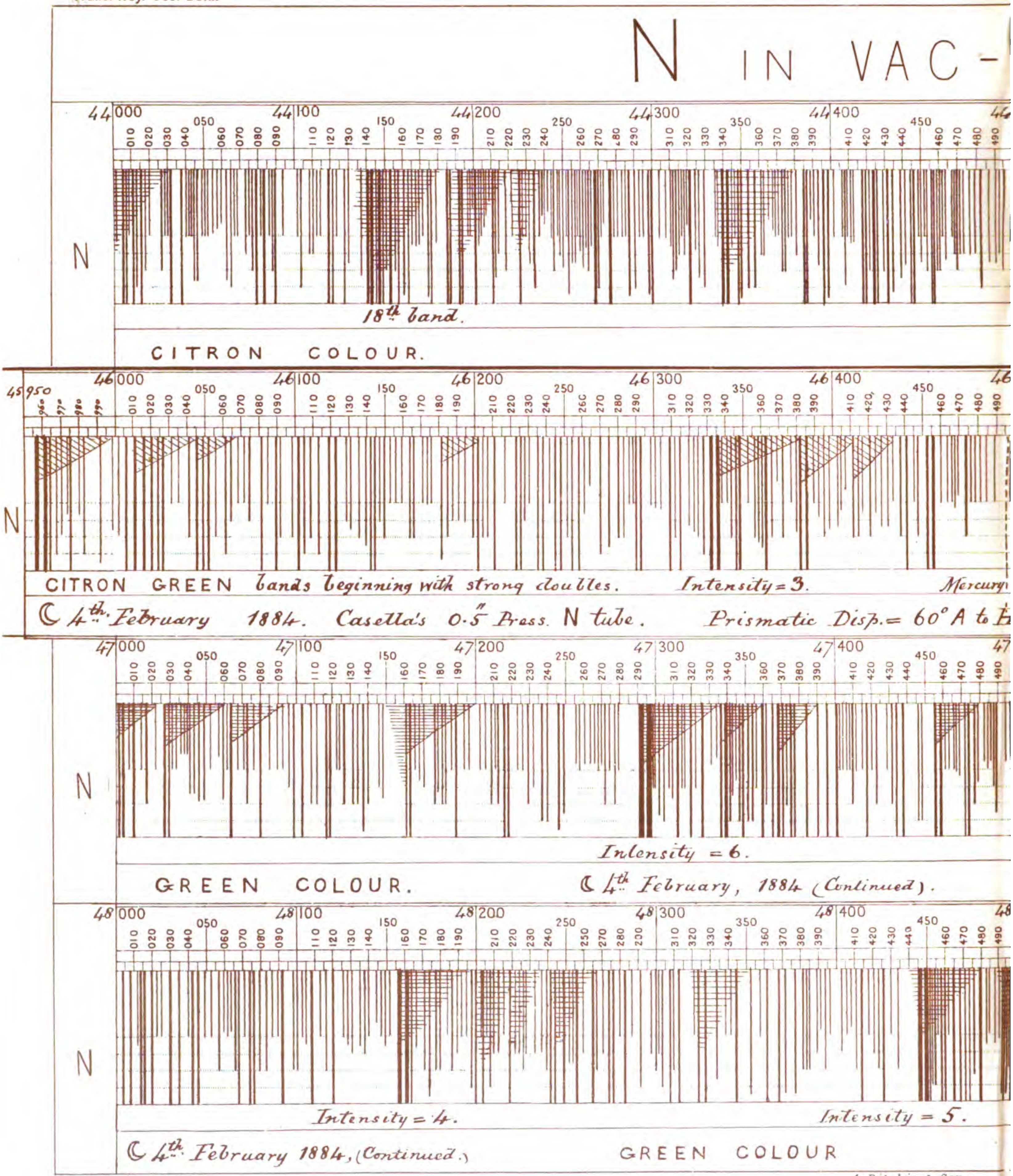

*14th band.*

N COLOUR. *Closeness and definition of the constituent lines inconceivable.*




*17th band.*

*Photo-Lith. 1884.* *T H del. 2.*




C.P.S. obs. & del. 1

A. Ritchie & Son.

-UUM - TUBES

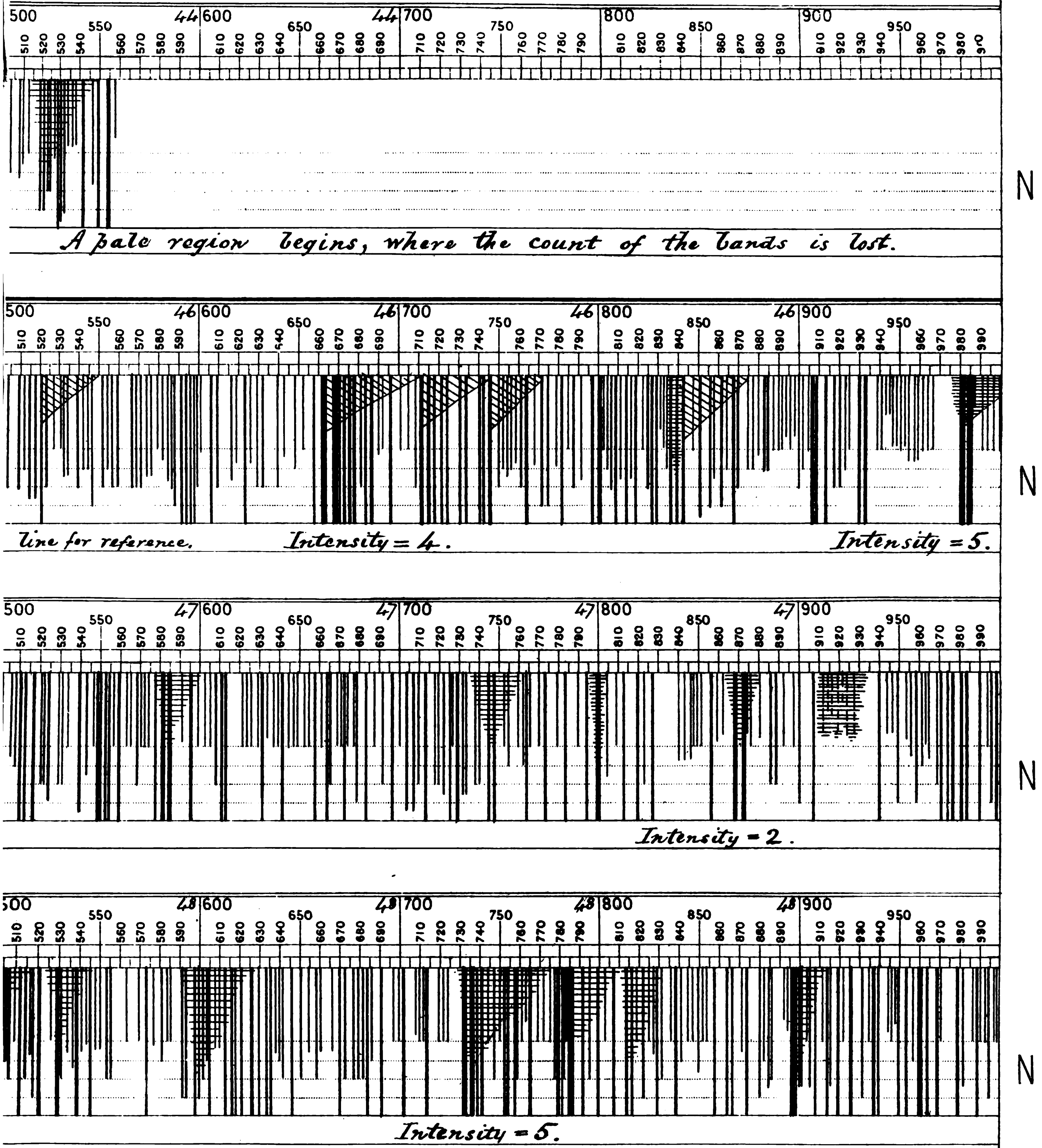
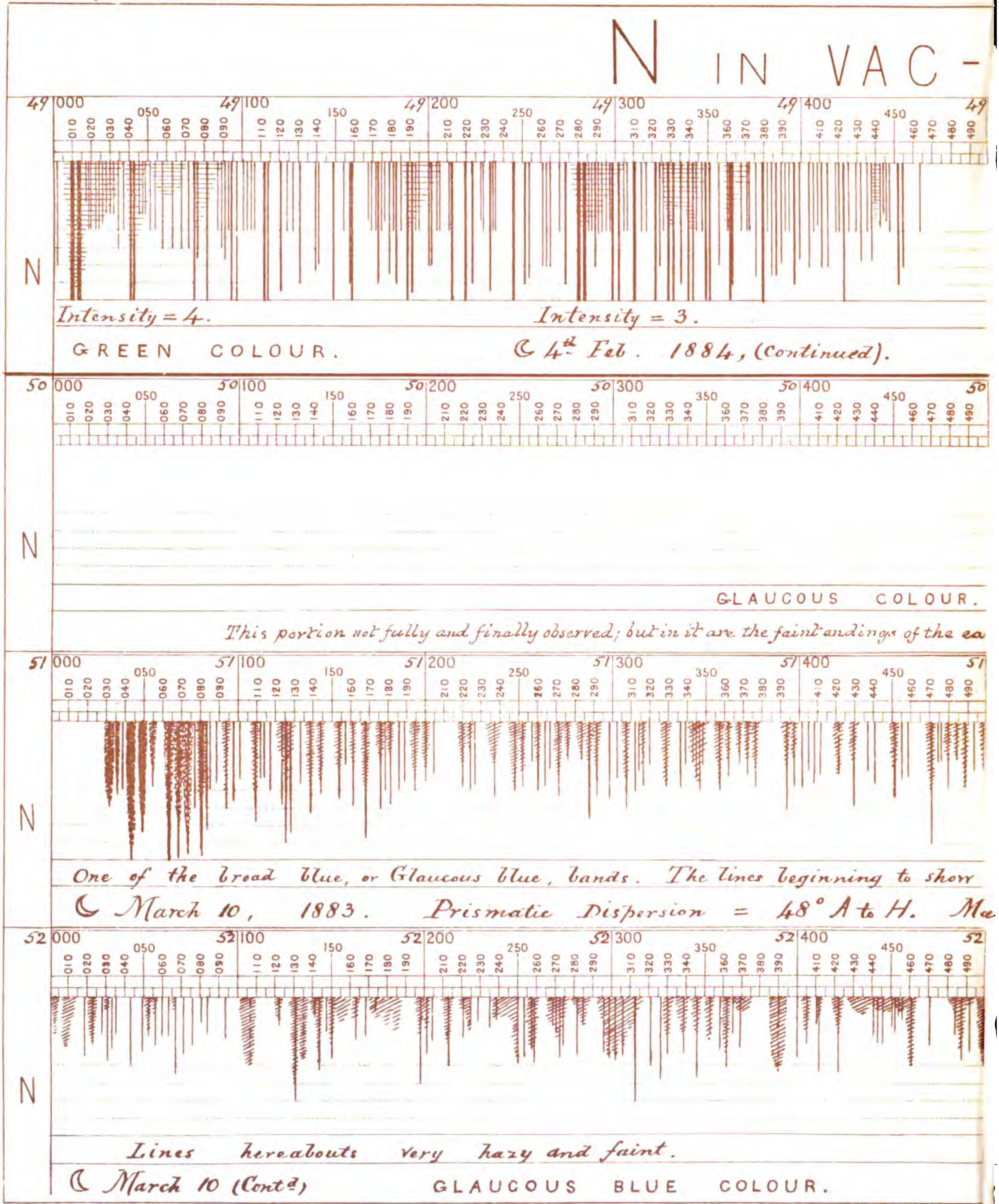



Photo-lith. 1884.

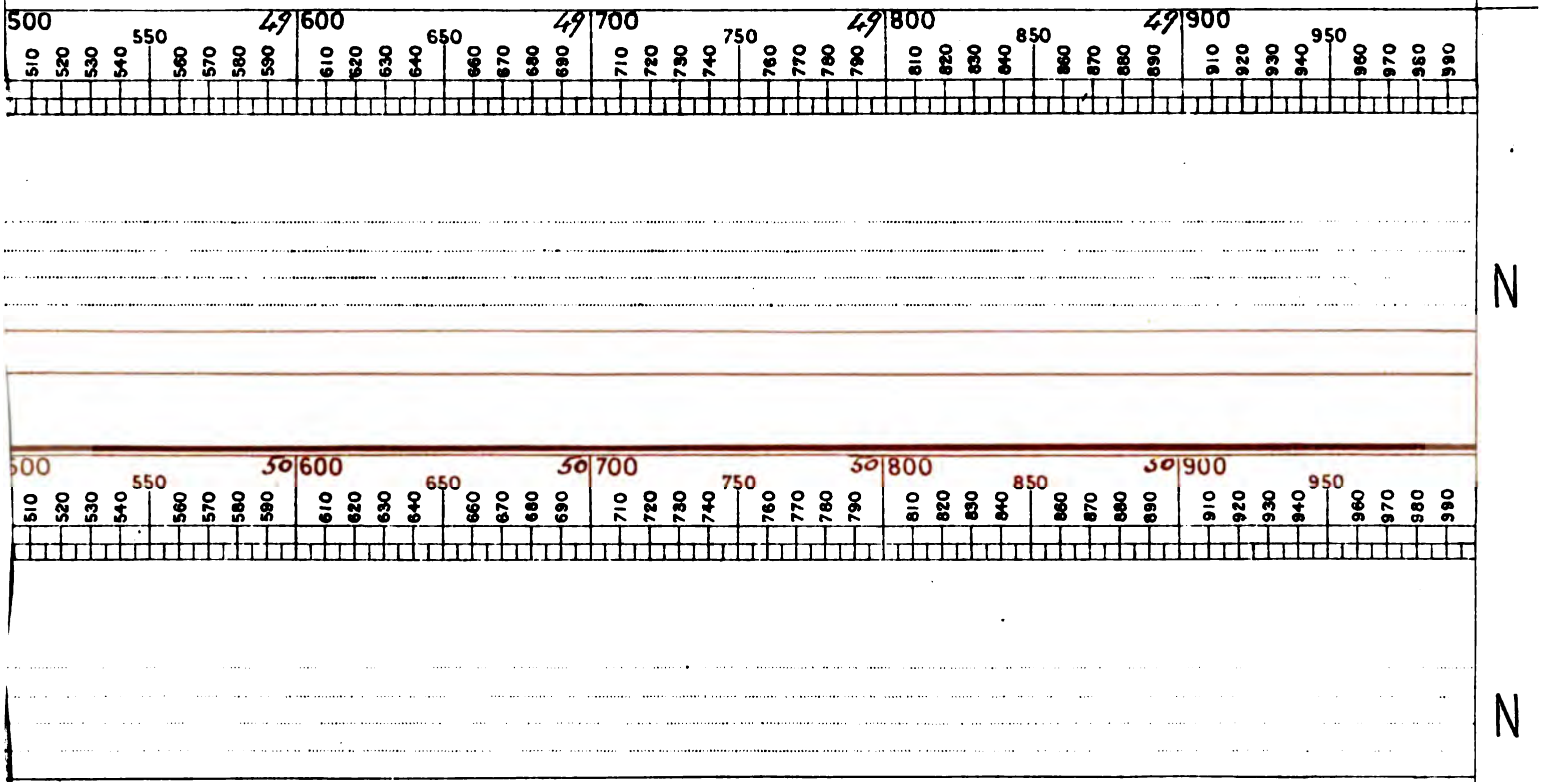
T. H. del. 2:



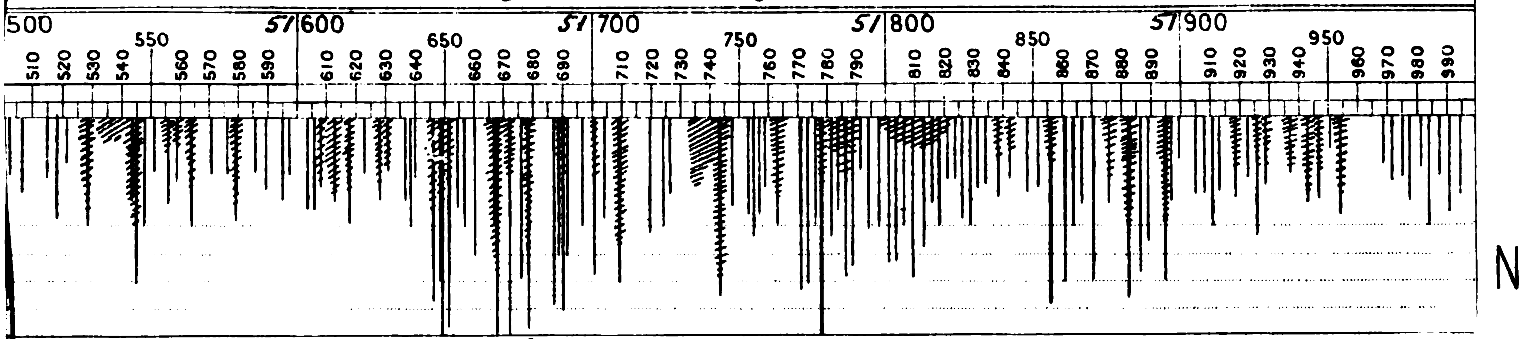

C.P.S. obs. & del. I.

A. Ritchie & Son.

# -UUM - TUBES

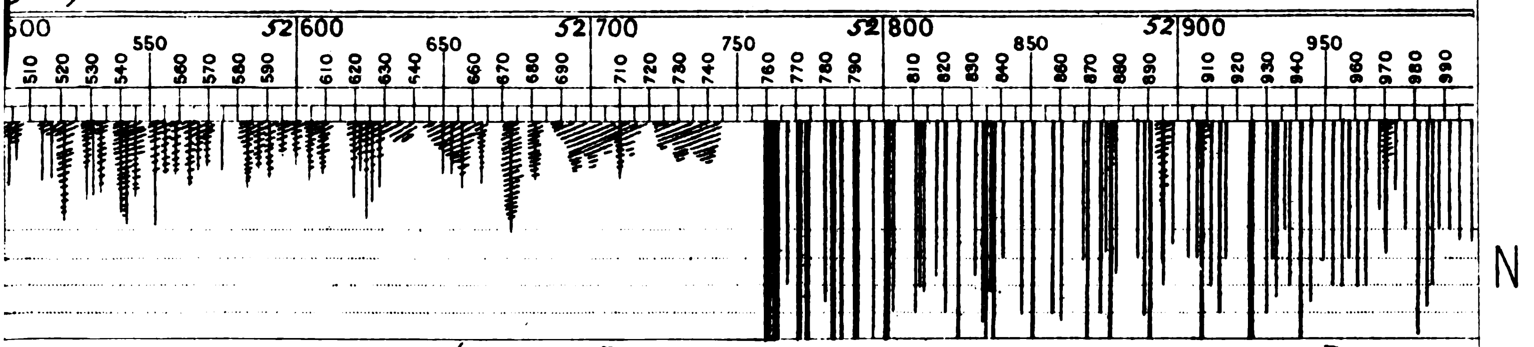



*-ylier narrow N bands, and faint beginnings of the broader, later or Violet bands of N.*




*-want of Definition. Another Glaucous-blue and broad band begins.*

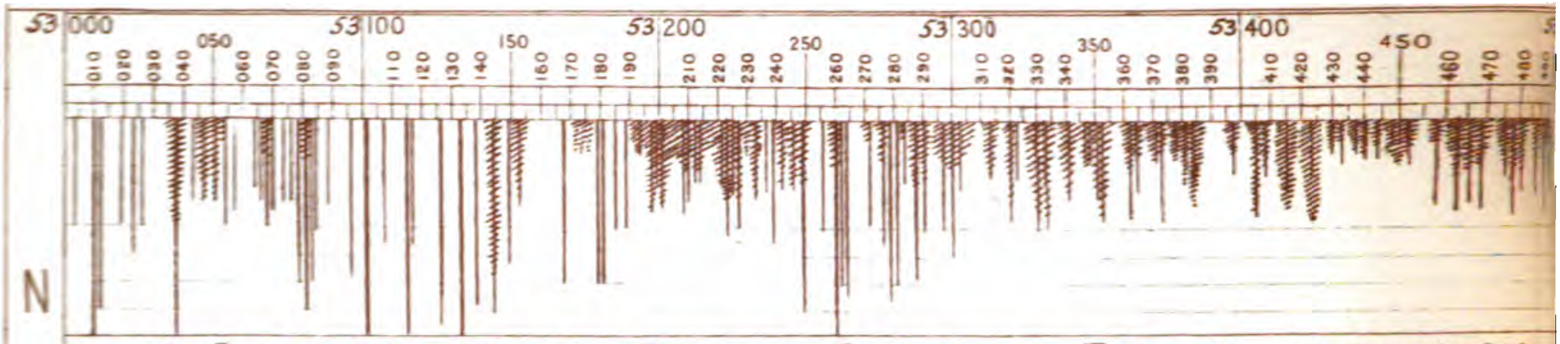
*-g! power = 21.*




*Strong beginning and well defined, of a broad band.*

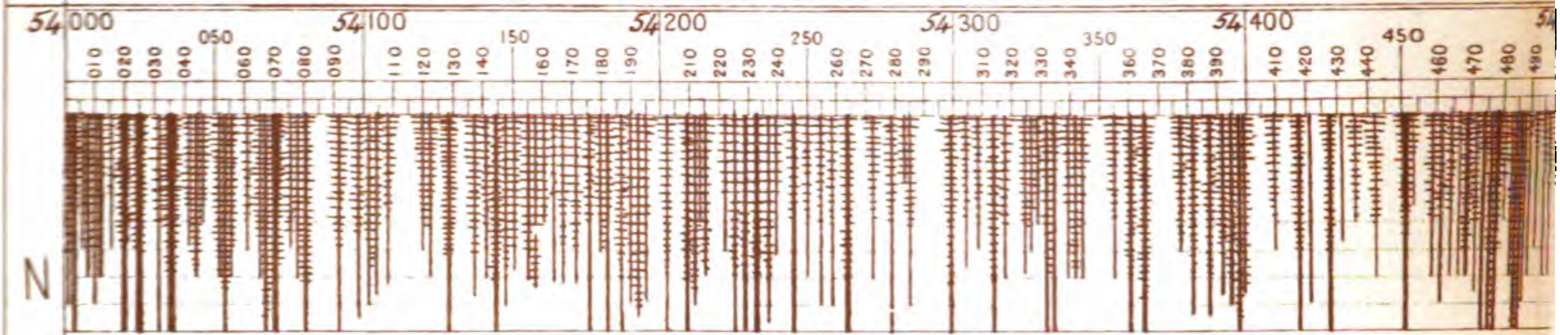
BLUE — BAND.

N IN VAC



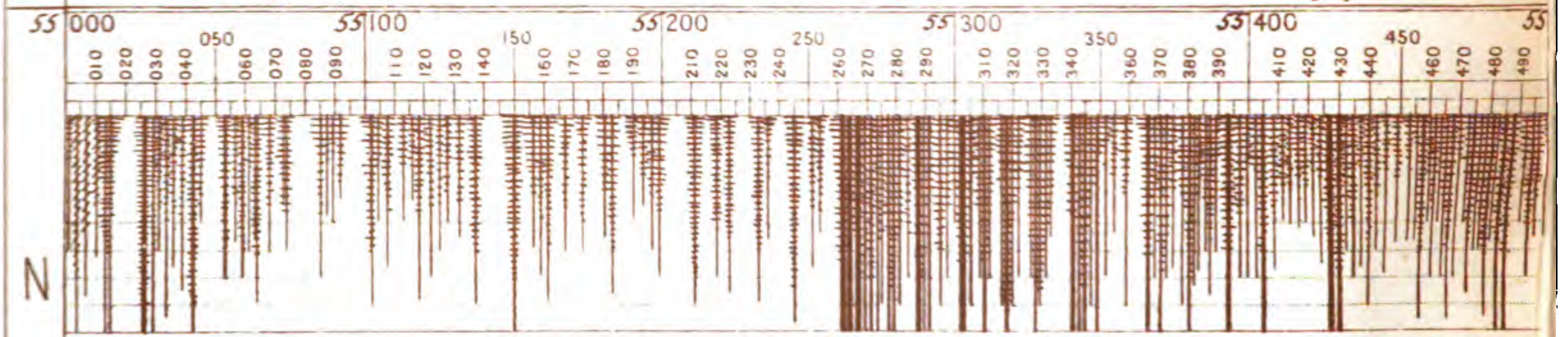

*The broad Blue - band's lines losing in Intensity and Definition*

☾ *March 10 Cont^d and Concluded.*



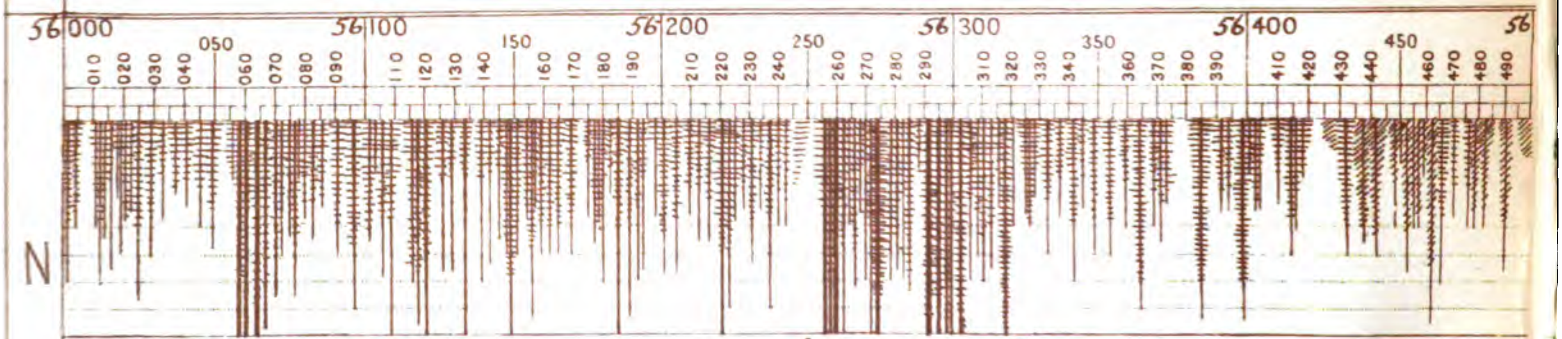

*beginning intruding on a Broad band.*

♃ *February 14, 1884. Prismatic Dispersion = 48° Mag. p. = 36.*




*Narrow beginning.*

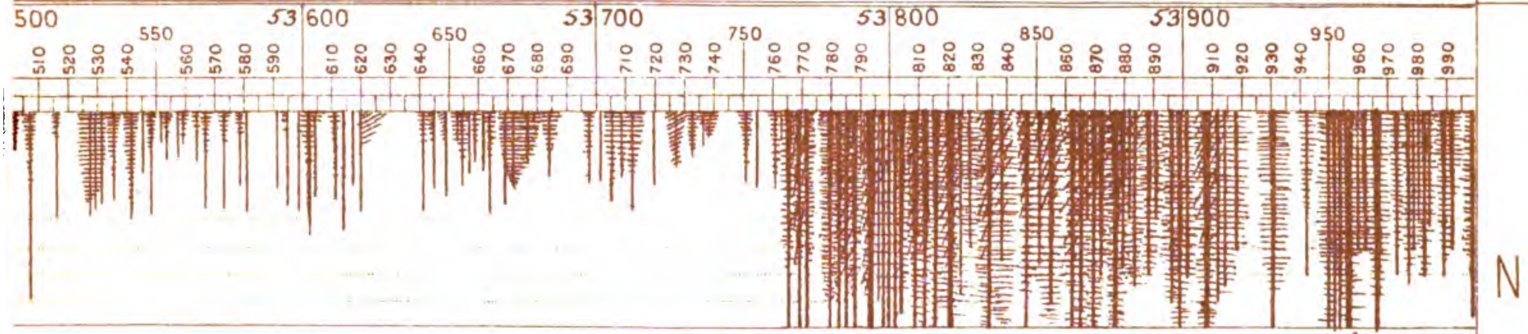
♃ *February 14, 1884. (Continued) A different order intruding.*




INDIGO COLOUR. *A narrow beginning.*

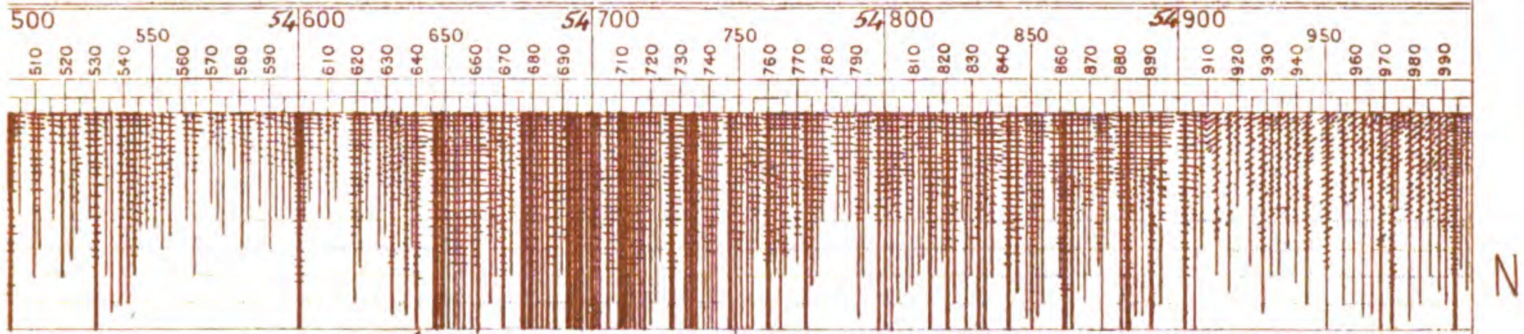
♃ *14^th February 1884, (Continued.)*

# -UUM - TUBES



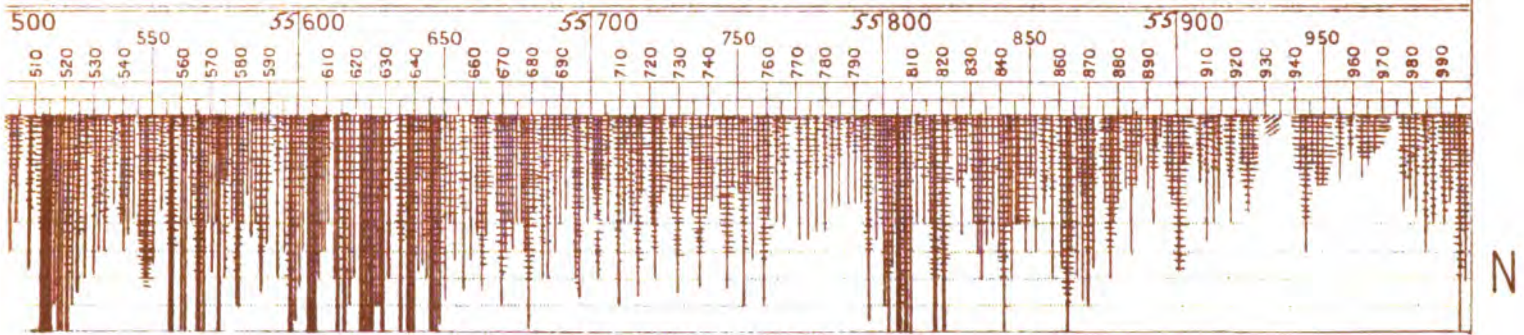

*Broad club beginning.* *A narrow*

*2 Feb. 14, 1884.*



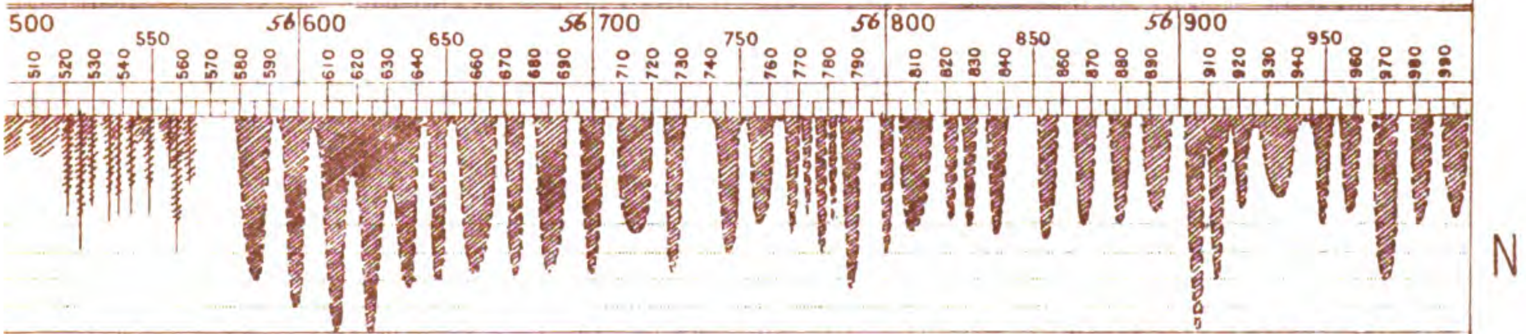

*A broad club beginning; of a broad band.*

BLUE COLOUR.




*Broad club beginning, of a broad band.*

INDIGO COLOUR.

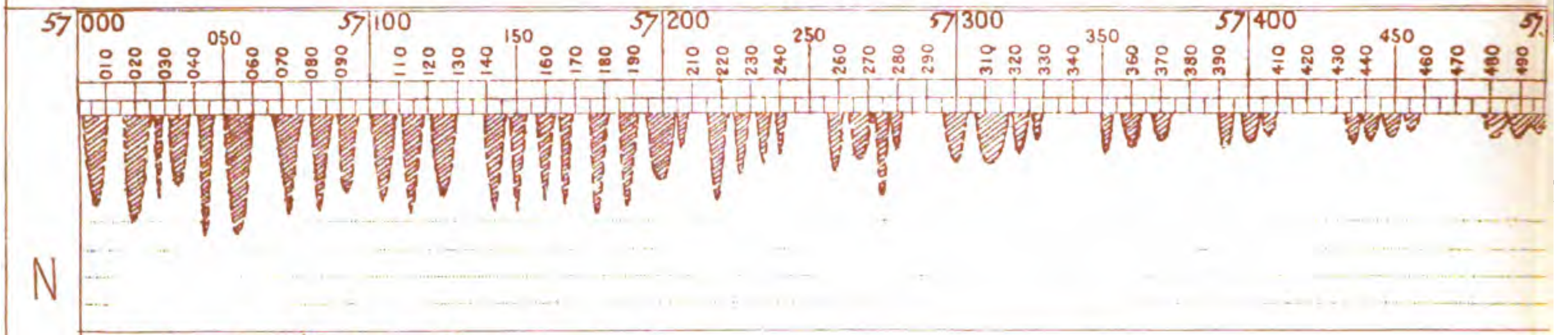



*Broad club beginning of broad, ill defined characteristic Violet band.*

*2 February 21. 1884. Casella's 0.5" Press.* N *tube.*

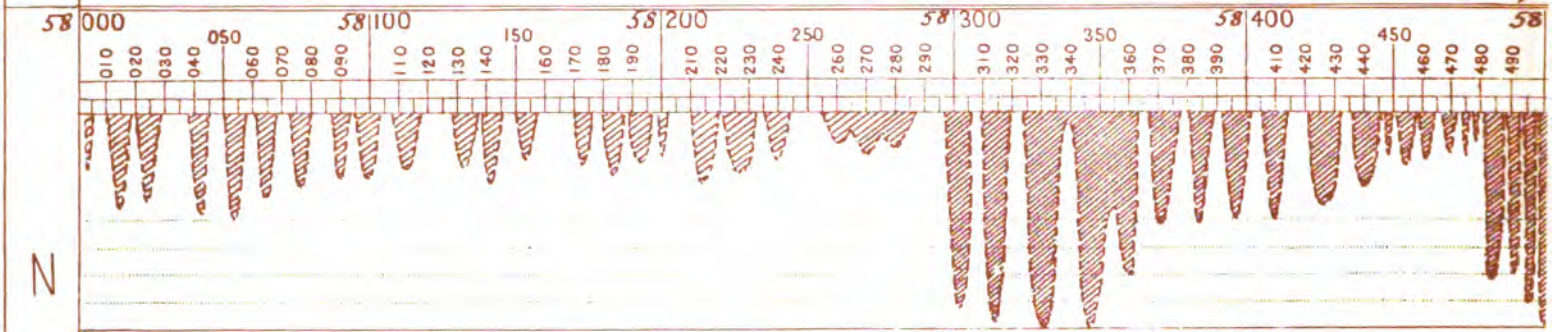
*Photo-lith. 1884.* *T. H. del 2*

# N IN VAC-



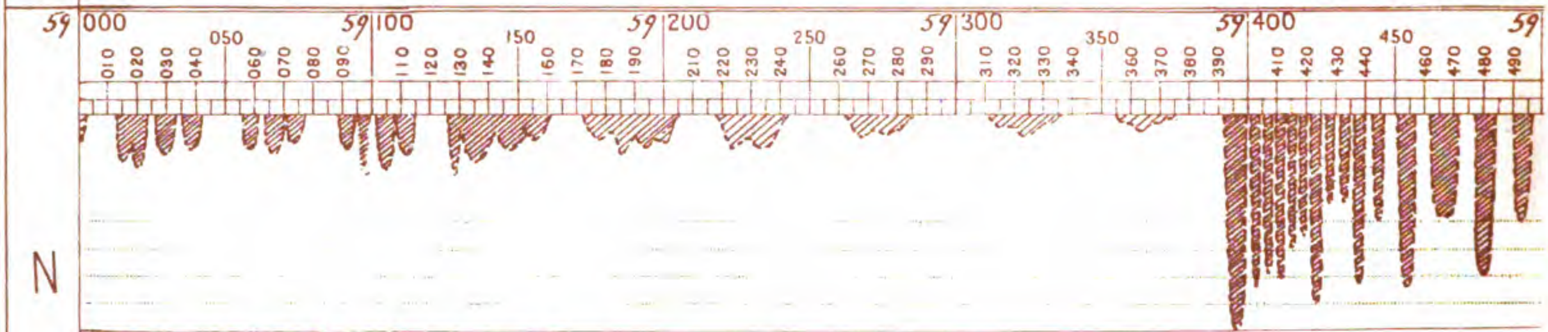

*The broad Violet band paling.*

*4 February 21, 1884. Prismatic Dispersion = 36° A to H. Mag.ⁿ p*



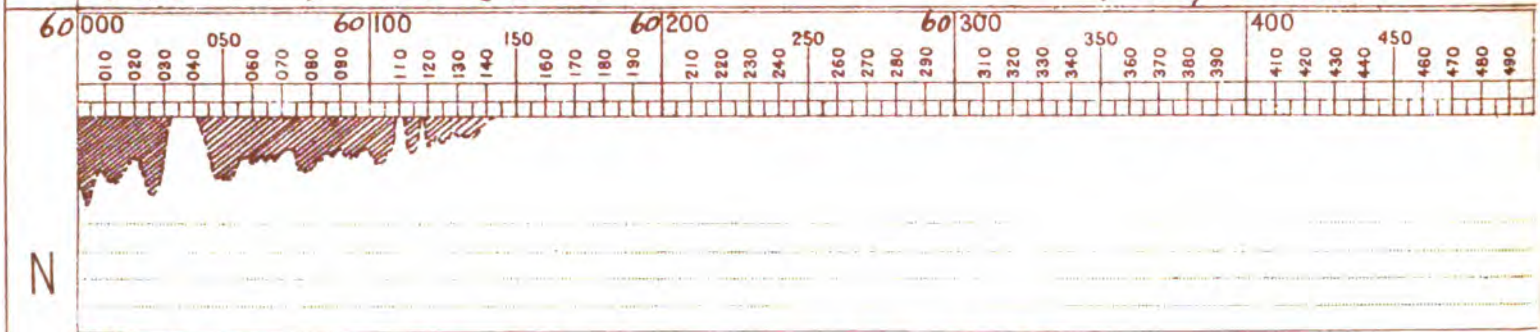

*Broad club beginning.*

*4 Febr. 21, 1884, (Cont.ᵈ)* VIOLET. *Shar*




*The broad Violet band paling.*

*4 Febr. 21, 1884 (Cont.ᵈ)* *Sharp Intruder: lives in*

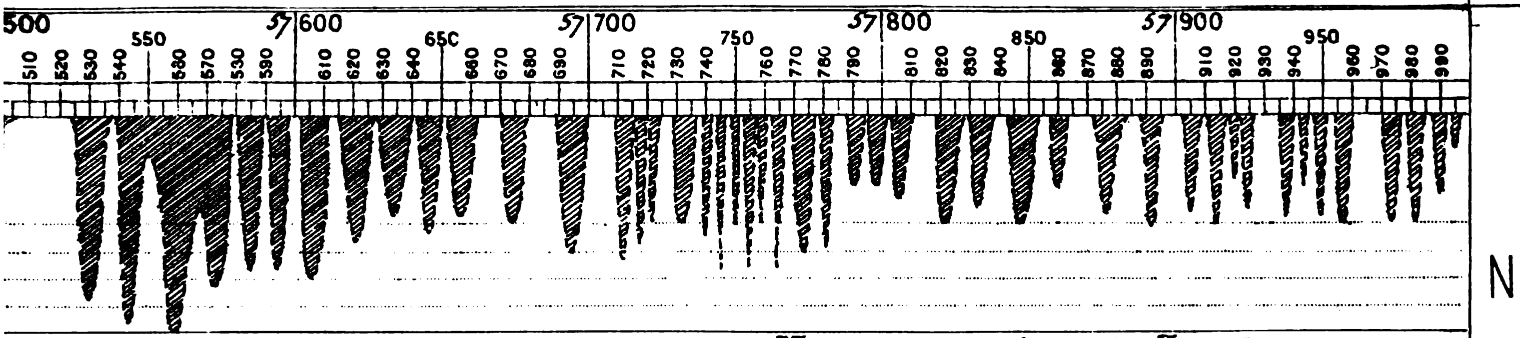



*An Intruder — but definition getting too bad.*

*4 Febr. 21, 1884, (Cont.ᵈ).*

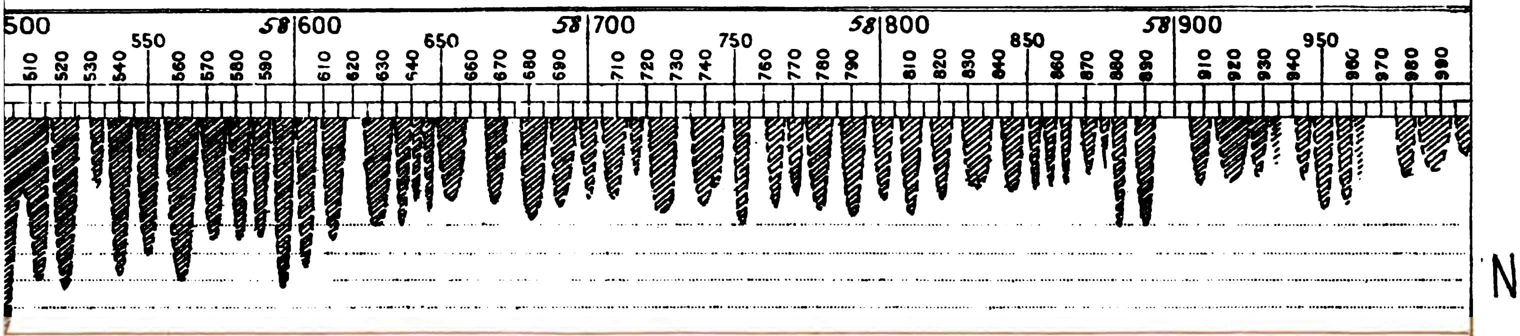
C.P.S. obs. & del. 1 A. Ritchie & Son.

# -UUM-TUBES ...

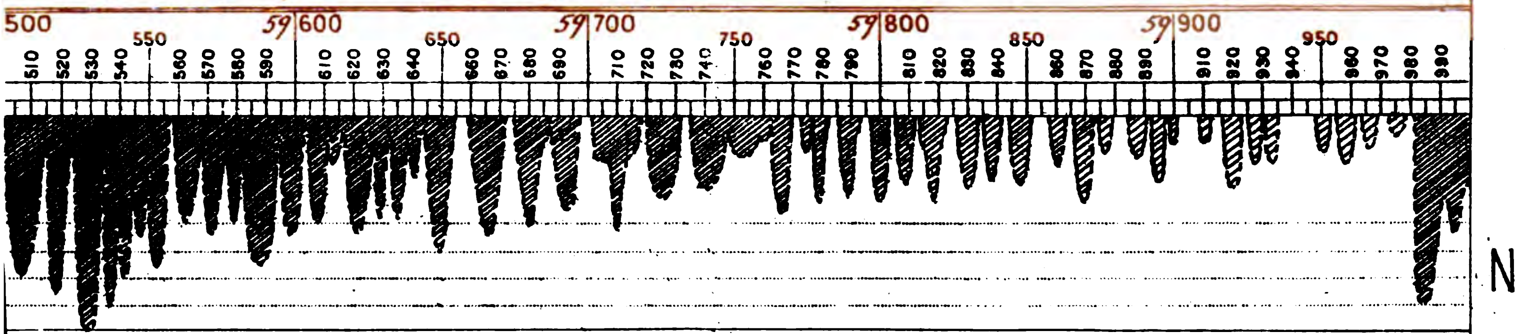



*Broad club beginning of broad ill-defined . Violet band.*

*= 21.*

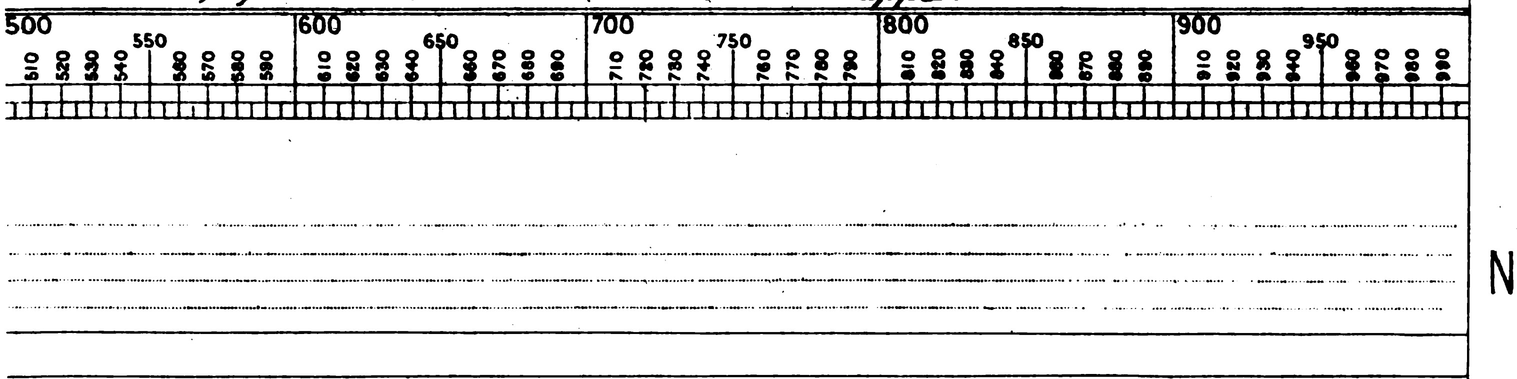



*per beginning of an intruding band.*




*road club beginning, of grandly broad Violet band.*

*old Tubes, after all the broad bands have disappeared.*



# LIST OF ALL THE PLATES CONTAINED HEREIN,

## *VIZ.* 29 DOUBLE-PAGE PLATES, AND 2 LONG FOLDING PLATES, AS BELOW.

| R. S. E.'S VOLUME NUMBER. | THIS PAPER'S NUMBER. | GENERAL SUBJECT. | PARTICULAR DETAILS. |
|---|---|---|---|
| XLVIII. | 1 | **CH** IN BLOW-PIPE FLAME; *on a 40 foot Spectrum length.* | *Orange band, and Citron band.* |
| XLIX. | 2 | | *Citron band continued, and Green band.* |
| L. | 3 | | *Green band continued, and Blue band.* |
| LI. | 4 | | *Violet band at the end thereof.* |
| LII. | 5 | *Characteristics of several methods of Gaseous-Incandescence. A single-page Representation.* | |
| LIII. | 6 | **CH** *again, but in Vacuum Tubes, and by Electric Spark.* | *Citron band and Green band.* |
| LIV. | 7 | | *Green, Blue, Violet and Marsh Vi. bands.* |
| LV. | 8 | **CO,** *in Vacuum Tubes, on the same 40 foot Spectrum length.* | *Red band and Scarlet band.* |
| LVI. | 9 | | *Orange band and Yellow band.* |
| LVII. | 10 | | *Yellow band and Citron band.* |
| LVIII. | 11 | | *Green band and Blue band.* |
| LIX. | 12 | | *Indigo band and Violet band.* |
| LX. | 13 | **H,** *in Vacuum Tubes, on same Scale.* | *Early Red, Red, and Scarlet, regions.* |
| LXI. | 14 | | *Orange, Yellow and Citron regions.* |
| LXII. | 15 | | *Citron to Green, region.* |
| LXIII. | 16 | | *Green, Glaucous, and Blue regions.* |
| LXIV. | 17 | | *Blue and Indigo regions.* |
| LXV. | 18 | | *Violet region.* |
| LXVI. | 19 | **O,** *in Vacuum Tubes, on same Scale.* | *Ultra Red, Red and Scarlet regions.* |
| LXVII. | 20 | | *Orange and Yellow regions.* |
| LXVIII. | 21 | | *Citron to Green, region.* |
| LXIX. | 22 | | *Glaucous to Violet, region. N.B.—The Glaucous-coloured Oxygen triplets at 50,630 and 51,160 W.N. Pl. respectively, should be decreased somewhat in intensity and size.* |
| LXX. | 23 | **N,** *in Vacuum Tubes, on same Scale.* | *Ultra Red region.* |
| LXXI. | 24 | | *Red and Scarlet, regions.* |
| LXXII. | 25 | | *Yellow and Citron, regions.* |
| LXXIII. | 26 | | *Citron and Green, regions.* |
| LXIV. | 27 | | *Glaucous and Blue, regions,* |
| LXV. | 28 | | *Blue and Indigo, regions.* |
| LXVI. | 29 | | *Violet regions.* |
| LXXVII. | 30 | *Long, folding, Index Map, on a very small Spectrum scale, of all the above, and some other, Gases, at both high, and low, Electric temperatures; intended to serve as a Frontispiece and useful Key, to the whole.* | |
| LXXVIII. | 31 | *Long, folding Plate of Green CO's extra CH's green, portion. Full size of original instrumental record, viz. on a 120 foot Spectrum length (A to H of Fraunhofer); with explication of its remarkable double Arithmetical Series of construction, by Professor Alex. S. Herschel, M.A., College of Science, Newcastle-on-Tyne.* | |